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Relationships among spatial and analytic components of learning style and achievement in college biology students

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The Ohio State University, 1991
RELATIONSHIPS AMONG SPATIAL AND ANALYTIC COMPONENTS OF LEARNING STYLE AND ACHIEVEMENT IN COLLEGE BIOLOGY STUDENTS

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

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* * * * *

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CHAPTER I

INTRODUCTION

Importance of the Study

The growing impact of science and technology on our daily lives demands a population that is scientifically and technologically literate. An increasingly sophisticated work force is essential for the country to experience continued economic growth. Additionally, a scientifically literate population is required to evaluate the increasing numbers of scientific and technological issues currently reaching national political agendas. Unfortunately, the science education report card for this country shows that the proportion of adults who have the ability to follow and understand these new scientific and technological issues is low. Moreover, studies of science achievement in school age children do not suggest that adult levels of scientific literacy will change in the near future if science education continues to follow its present course. The most recent study by the International Association for the Evaluation of Educational Progress (IEA, 1988) showed that U.S. fifth grade students ranked 8th among 15 countries in science achievement and U.S. 9th grade students ranked 15th among 16 countries. Studies within the country have shown a consistent decline in the science
achievement scores of high school students as measured by national assessments of science in 1969, 1973, and 1977 (Gardner, 1983).

When the scientific competency of the adult population is considered, the situation is even more alarming. Over the past decade, Miller (1983, 1989) has been monitoring the level of scientific literacy in the general population. Rather than implying an ideal or even an acceptable level of understanding, Miller considers the concept of scientific literacy to represent a threshold value marking the minimal level of scientific knowledge and understanding needed to function effectively as citizens and consumers in today's society. Results of a 1988 study using his three-part instrument which assesses an individual's knowledge of scientific and technical terms, understanding of the nature of science, and understanding of the interrelationships between science and society indicate that only one in twenty American adults meets a minimal definition of scientific literacy (Miller, 1989). A literacy rate of only 7% was observed in an evaluation (Miller, 1988) of the scientific literacy level among American high school sophomores conducted the same year, indicating that the level of scientific literacy in the general population is unlikely to rise when the current cohort of high school students graduates. Clearly there is a need to evaluate science education practices at all levels if the downward trend in science achievement levels is to be reversed.

Recent examinations of practices in science education have revealed that science instruction is oriented almost exclusively
toward providing scientific facts necessary for advanced coursework in science (Harms & Yager, 1981). Rather than addressing the broad goals encompassed in a definition of scientific literacy such as preparation to use science in everyday life and preparation to vote responsibly on science-related societal issues, teachers focus narrowly on preparation for future science classes. A 1987 study of science teachers by Mitman, Mergendoller, Marchman, and Packer (1987) demonstrated that the teachers presented academic information exclusively and rarely, if ever, made explicit references to the societal or attitudinal implications of their subject matter. Additionally, results of the most recent National Survey of Science and Mathematics Education (Weiss, 1987) indicated that science teachers perceive their most important objective to be the dissemination of basic scientific facts and principles to their students. With respect to other components of scientific literacy, only four out of ten teachers reported an emphasis on technology in their lessons and only three out of ten reported including discussions of the career relevance of various topics. Studies such as these suggest that the current practices of science teachers do not reflect the broad goals of science education established by the National Science Teachers' Association (Harms & Yager, 1981).

One explanation for the emphasis on a body of facts in science classes is the overwhelming dominance of science textbooks as the major component of curriculum. Stake and Easley (1978) reported that 90 to 95 percent of 12,000 elementary and secondary teachers
surveyed indicated that they rely on the text as the sole component of curriculum 90 percent of the time. An evaluation of the most widely used science texts shows that most are completely devoid of references to science for personal needs or the relationship between science and technological advances and societal issues (Harms & Yager, 1981). Instead, the majority of texts are compendiums of discrete scientific facts which encourage instruction emphasizing rote memorization. This is especially true of college science texts where the desire to relay current knowledge leads to texts packed with unmanageable amounts of information couched in specialized scientific terminology. In the 1950s the average length of a college science text was around 600 pages; in the 1980s, around 1200 pages (Blystone, 1987). The encyclopedic nature of college science texts leads students to view science as a dry, taxing endeavor suitable only for students with outstanding memory capabilities (Wivagg, 1987). The situation is further compounded by the overwhelming reliance on lecturing as the primary mode of instruction at the college level, especially in large introductory courses for nonmajors. Though lectures can be used as an effective and interesting method of instruction, students in large nonmajors courses often find them to be disorganized and lacking in enthusiasm. One possible explanation for this is that professors are often assigned to teach these courses as a punishment for an unproductive publication record (Carlson, 1981). Additionally, nonmajors are often perceived by the science faculty as less able than majors and not worthy of more than a superficial
overview of as many topics as can be "covered" during a school term (Dean, 1978).

If the overall level of scientific literacy in the population is to improve, science courses must be altered to contain manageable quantities of information presented using a variety of methods designed to require a variety of cognitive skills. Revision is especially in order for introductory level college science courses which may represent the last formal science instruction many individuals receive. Rather than being treated as an introduction to the next course, these courses need to be viewed as opportunities to generate enthusiasm toward science, to encourage students to study further on their own, and to develop the thinking skills necessary to evaluate science-related issues in the adult world (Dean, 1978). The need for this type of focus in nonmajors courses is even more critical in the present than it has been in the past because the proportion of undergraduates who elect nonscience majors continues to climb while the proportion of science majors dwindles. After reaching a peak in 1986, the number of B.S. degrees awarded in the natural sciences and engineering has declined each year. Based on this trend, the National Science Foundation predicts that by the year 2006 there will be a cumulative shortfall of 400,000 B.S. degrees in science and engineering (Massey, 1989). One obvious consequence of decreasing numbers of science majors is an increase in enrollment in introductory level courses for nonmajors. These introductory courses represent a "last chance" to provide an adequate science content
background to the future lawyers, business executives, legislators, and journalists who will decide on the values and laws that determine the progress of science and technology for future generations (Carlson, 1981). Clearly, there is a need to critically examine and evaluate introductory level science courses for nonmajors to determine how they can be altered to more effectively address the goal of universal scientific literacy.

Reform efforts in undergraduate science education need to focus particularly on strategies which would contribute to the attainment of scientific literacy by female students. Findings from Miller's latest scientific literacy poll (1989) demonstrated that males were significantly (p<.01) more likely to be scientifically literate than females, even when the respondents' level of formal education and enrollment in college level science courses were held constant. Data from studies at the pre-college level suggest that males and females often have unequal educational opportunities within the same science classroom (Kahle & Lakes, 1983). Miller's findings suggest that the same problem may exist at the college level. However, even if women are being provided with equal educational opportunities in college level science courses, it is clear from national statistics that factors exist which lead fewer females to select science-related careers. For example, U.S. employment records indicate that, although approximately 50% of employed adults are women, only 25% of scientists and 5% of engineers are women (Massey, 1989). Additionally, a demographic analysis of recipients of doctorates from
U.S. universities in 1989 revealed that the proportion of doctoral degrees in scientific disciplines conferred upon women was only 38.2% for the life sciences, 18.8% for the physical sciences, and 8.2% for engineers ("Fact File," 1989). These statistics support the need for research directed specifically at improving the experience of women in introductory level science courses as a potential avenue for increasing the number of women who choose to continue in science.

A relatively new area of research is providing evidence that reliance upon lecturing or any other single method of instruction limits achievement levels across students. It is now known that individuals have preferred ways of receiving and processing incoming information which have been referred to as a part of each individual's "learning style." There is growing evidence to suggest that modifying instruction to match the preferred learning styles of students increases achievement levels and leads to more positive attitudes toward the learning experience. Studies (e.g. Douglass, 1979; Tanenbaum, 1981; and Dunn & Griggs, 1988) showing positive effects with respect to science achievement and attitudes toward science support the need for continued research in the area of learning styles as a potential means of improving science education at all levels and ultimately increasing the level of scientific literacy in the general population.

Miller's (1989) most recent study of scientific literacy indicated that the completion of college science courses is the most reliable
predictor of whether or not an individual will be scientifically literate. Specifically, when the variables age, gender, level of formal education, employment in a scientific firm, and number of college science courses completed were examined to determine their relationship to scientific literacy, the variable representing number of college science courses completed accounted for 39% of the variance in scientific literacy scores. Each of the other variables accounted for 10% of the variance or less. This finding suggests that learning styles research is especially warranted in populations of undergraduate nonscience majors as a method of uncovering ways to increase student achievement levels and attitudes toward science in introductory level science courses. Greater achievement and more positive attitudes stemming from students' first college science experiences are likely to increase the possibility of students enrolling in additional science courses. Since completion of college science courses correlates strongly with scientific literacy, increasing enrollments in college science courses could be an effective means of increasing the level of scientific literacy in the general population.

**Background for the Study**

At a large midwestern university, the learning styles of students enrolled in an introductory level biology course for nonscience majors were recently evaluated. The course, which has now been replaced by a new introductory level course, was taught by the audiotutorial method in which students received instruction
on an individual basis by listening to taped lectures, completing laboratory exercises, and attending biweekly recitation sessions (Meleca, 1973). Students listened to the lectures in individual carrels in the Bio-Learning Center (a facility staffed by teaching assistants) which also contained a central lab station in addition to the individual carrels. The audiotutorial program was implemented in 1969 and continued until Summer Quarter of 1990, serving approximately 3,500 students each year. During the years of its existence, the only major alteration to the course was the addition of computerized testing facilities in the 1970s. After the addition of these facilities, student grades for the course were based entirely upon their performance on computer administered tests drawn from an extensive bank of test questions.

Knowing that the course had not been evaluated since it began in 1969, the director of the course instituted a major evaluation and assessment effort in 1988 to determine what format of the course would best suit the students it was designed to serve. As a part of the evaluation process, the learning styles of 973 students enrolled in the course during Winter quarter of 1988 were assessed using the Learning Style Profile (LSP), an instrument developed by the National Association of Secondary School Principals (Keefe & Monk, 1986). A comparison of student LSP scores with student course grades revealed a significant ($p<.0001$) correlation between LSP spatial score and biology achievement (Melear, 1989). Significant correlations were not found for other variables included in the LSP
such as environmental preferences, affective preferences, and other
cognitive abilities including memory, categorization, discrimination,
and analytic skill. However, in a factor analysis of LSP items two of
the five analytic items loaded with the items designed to measure
spatial skill (Melear, 1989), indicating that analytic ability may also
be linked to student performance in the course. The developers of
the LSP also reported that some analytic skill items loaded with the
spatial skill items in a factor analysis (Keefe & Monk, 1986)
supporting the findings of Melear and suggesting that the LSP
analytic and spatial subscales are actually measures of the same
variable or very similar variables.

The analytic subscale of the LSP was modeled on the Embedded
Figures Test developed by Herman Witkin as a measure of the
cognitive style of field dependence versus independence (Keefe &
Monk, 1986). Field independent individuals perceive things as
distinct or independent of their surrounding field or context while
the perceptions of field dependent individuals are strongly
influenced by context (Witkin, 1969). The subscale consists of items
which require subjects to disembed a simple figure from a more
complex figure. Positive correlations between measures of spatial
ability and such disembedding tests have been found so frequently
that Linn and Kyllonen (1981) have suggested that disembedding
tests are actually tests of spatial ability. If the analytic subscale of
the LSP is actually an additional measure of spatial skill rather than
a measure of a separate cognitive factor, then the findings of Melear
(1989) indicate that spatial skill is the only LSP variable significantly correlated with biology achievement in non-majors.

Significant correlations between disembedding ability, measures of spatial skill, and chemistry achievement were reported by Bodner and McMillen (1986) and Carter, LaRussa, and Bodner (1987). Bodner and McMillen refer to disembedding as cognitive restructuring. They suggest that spatial ability, including disembedding or restructuring ability, is necessary to complete the early stages of problem solving in which students must disembed relevant information from the problem and then restructure or rearrange that information into a question they can understand. According to this model of problem solving, spatial ability is a key factor in all problem solving tasks, even those with no obvious spatial component.

Findings from other studies (Guay, McDaniel, & Angelo, 1978; Guay & McDaniel, 1978, Kyllonen, Lohman, & Snow, 1984) do not support the conclusion that disembedding or analytic skill measures are actually measures of spatial skill. Instead, these studies suggest that correlations between disembedding tests and measures of spatial skill are observed because some items on purported assessments of spatial skill can be solved using analytic processing strategies and, therefore, are not valid measures of spatial skill. Additionally, Guay, McDaniel, and Angelo (1978) and Kyllonen, Lohman, and Snow (1984) report that subjects often change solution strategies within the same spatial test shifting from spatial to
analytic processing depending on the difficulty of the item. Kyllonen, Lohman, and Snow (1984) administered a revised version of the Paper Folding Test (Elkstrom, French, & Harman, 1976) and found that subjects used both analytic and spatial strategies to solve the problems. Subjects reported that their selection of strategy was influenced by the number of folds and the symmetry of the folds.

Three of the five items on the spatial subscale of the LSP are paper folding items. The developers of the LSP claim that these items are measures of the spatial visualization component of spatial skill. However, the findings of Kyllonen, Lohman, and Snow (1984) indicate that these items may not be valid measures of spatial ability since individuals often shift between spatial and analytic processing when solving paper folding tasks. Since two of the LSP analytic subscale items loaded with the spatial subscale items in a factor analysis (Keefe & Monk, 1986; Melear, 1989) it is possible that the significant correlation between LSP spatial score and biology achievement observed by Melear (1989) was actually indicative of a relationship between analytic ability and biology achievement.

The LSP was designed to be a first level diagnostic instrument to provide information about a wide variety of variables within a large group of subjects (Keefe & Monk, 1986). Preliminary research using the LSP suggests that a student's spatial skill level is a potential predictor of whether the student will succeed in a non-majors biology course. However, since the LSP contains a relatively small number of items per subscale and was not originally designed
for use with post-secondary populations, a more reliable and appropriate method of assessing spatial skill needs to be obtained for this population. Additionally, further research is needed to clarify whether spatial skill and analytic skill are actually two distinct cognitive factors and whether spatial skill, analytic skill, or both skills are influential with respect to biology achievement.

In a pilot study for the proposed research (Sutherland, 1990), the spatial and analytic skill levels of a sample of non-biology majors were assessed using five commonly used measures of spatial and analytic ability. These measures included the Purdue Visualization of Rotations Test (Guay, 1980), the Mental Rotations Test (Vandenberg & Kuse, 1978), the Hidden Figures Test (Elkstrom, French, & Harman, 1976), the Card Rotations Test (Elkstrom, French, & Harman, 1976), and the Paper Folding Test (Elkstrom, French, & Harman, 1976). Reliability estimates for the five instruments ranged between .76 and .98, indicating that these instruments provide a more reliable means of assessing spatial and analytic skill than the spatial (α=.60) and analytic (α=.56) subscales of the LSP.

An analysis of scores on the five instruments provides evidence that spatial and analytic skill are two distinct cognitive factors. Pearson product-moment correlations among the Purdue Visualization of Rotations Test (ROT), the Mental Rotations Test (MRT), the Card Rotations Test (CRT), and the Paper Folding Test (PFT), four instruments designed to measure spatial skill, and the Hidden Figures Test (HFT), a purported measure of analytic skill,
show a significant correlation between only one of the spatial skill measures and the HFT. Moreover, a factor analysis of the five total scores indicates two separate factors. The HFT loads strongly on one factor while three of the spatial skill assessments load strongly on the other factor. The fourth spatial measure, the ROT, loads moderately on both factors. Although the preliminary data strongly suggest that spatial skill and analytic skill are two distinct cognitive factors, the small sample size (n=51) employed suggests the need for additional factor analysis of scores on these instruments to determine whether they measure two separable cognitive constructs.

With respect to the relationship between spatial and/or analytic ability and biology achievement, the findings of the pilot study provided additional evidence supporting the hypothesis that spatial skill is positively correlated with achievement in biology. Specifically, a group of items designed to measure the visualization component of spatial skill demonstrated a significant correlation with a composite biology achievement score. When achievement results were examined separately, the spatial visualization items were significantly and positively correlated with three of six achievement measures including a mid-term examination, a laboratory exam, and a laboratory practical. These findings suggest that spatial visualization skills may be particularly important for success in the practical aspects of biology and in the application of learned concepts to concrete situations. Although scores on the spatial orientation factor were not significantly correlated with the composite
achievement score, a significant correlation between spatial orientation and the laboratory exam was evident, indicating that the orientation component of spatial skill is also related to the application of biology concepts in laboratory environments.

The hypothesis that analytic ability is related to success in a non-majors biology course was not supported by the pilot data. Scores on the HFT were not significantly correlated with any of the six achievement measures. Additionally, scores on a subset of items which included only those items with factor loadings greater than .50 demonstrated a positive correlation with only one of the biology achievement measures.

Results reported by Bodner and McMillen (1986), Carter, LaRussa, and Bodner (1987), and Pribyl and Bodner (1987) indicate a significant relationship between spatial skill and chemistry achievement. However, in these studies the ROT and a test of disembedding ability were employed as measures of spatial skill. The findings of the pilot study indicate that disembedding ability represents a factor separate from spatial ability and that the ROT loads on both factors, suggesting that the previous studies actually indicate a significant correlation between analytic ability and chemistry achievement. A similar relationship between disembedding or analytic ability and biology achievement is not supported by the pilot findings. Since past studies have indicated a significant relationship between disembedding ability and science
achievement, further research is warranted to examine the relationship between analytic ability and biology achievement.

Future research should also focus on the relationship between spatial visualization and biology achievement. In addition to the findings of the present study, significant positive correlations between spatial visualization and biology achievement have been reported by Lord (1987b) and Costello (1985). Future research is needed, however, to identify the specific concepts within the field of biology or the types of items on biology assessment measures that require spatial visualization skills. In a study of the relationship between spatial skills and genetics items, Costello (1985) found that scores on the Paper Folding Test, a spatial visualization measure, loaded on the same factor as did five genetics items. Other items did not load with the spatial visualization measure, suggesting that spatial visualization skills are important in learning some, but not all, biological concepts. Further research examining individual biology items is needed to clarify which topics, item types, and/or types of concepts require spatial visualization strategies.

Problem Statement

The purpose of the present study was to further examine the relationships among spatial skill, analytic skill, and biology achievement in non-biology majors enrolled in a general biology
course. The goals of the research were to provide additional evidence as to whether spatial skill and analytic skill are two distinct cognitive constructs and whether knowledge of student spatial and/or analytic skill level can be used to identify students or student groups who are at risk of low achievement in biology. An additional goal was to identify the specific biology topics, types of items, or types of concepts that may be correlated with spatial and/or analytic ability.

**Limitations**

1. The population of Biology 101 students is self-selected so the sample used for the study was not a random sample from the overall population of non-biology majors.

**Delimitations**

1. The study was limited to Biology 101 students who volunteered to complete the spatial and/or analytic assessments in exchange for bonus points toward their course grade.

2. Measures of learning style were limited to the cognitive variables spatial and analytic skill.

3. Measures of spatial and analytic skill were limited to paper-and-pencil instruments.

4. Measures of biology achievement were limited to final examination scores from Biology 101.
Assumptions

1. It was assumed that the sample of volunteers from Biology 101 who participated in the study constituted a representative sample from the population of non-biology majors at The Ohio State University.

2. It was assumed that the participants completed the instruments chosen to measure spatial and/or analytic skill to the best of their ability even though they were not a required part of the course.

3. It was assumed that outside influences and experiences did not effect spatial and/or analytic skill during the course of the quarter so that correlations between spatial and/or analytic skill levels determined during the third week of the quarter and final examination scores were not significantly different than if spatial and/or analytic skill assessment had taken place concurrent with the achievement assessments.

4. It is assumed that since all students within a particular lecture section attended the same lectures and completed the same laboratory activities they received equivalent biology instruction during the quarter even though different recitation leaders were involved.

Definition of Terms

Analytic skill-- the ability to identify individual components of a field as distinct from their background (Keefe, 1988). This
construct is often measured by disembodged tests which have been correlated with spatial skill (Linn & Kyllonen, 1981).

Cognitive style-- a learner's distinct and consistent patterns of perceiving, organizing, and retaining information (Keefe, 1987).

Learning style-- the NASSP task force on learning style defines the construct as, "The composite of characteristic cognitive, affective, and physiological factors that serve as relatively stable indicators of how a learner perceives, interacts with, and responds to the learning environment" (Keefe, 1987).

Spatial skill-- a cognitive process generally considered to consist of two components. Spatial orientation has been described as the ability to remain unconfused by changing orientations in which visual stimuli are presented (McGee, 1979). Spatial visualization refers to the ability to mentally rotate objects in space (Keefe and Monk, 1986).

Research Hypotheses

1. Spatial skill and analytic skill are two distinct cognitive factors.

2. Some of the items on instruments designed to measure spatial skill are actually measures of analytic skill.

3. Spatial skill is positively correlated with achievement in a nonmajors biology course.

4. Analytic skill is positively correlated with achievement in a nonmajors biology course.
These hypotheses will be tested in null form.
CHAPTER II
REVIEW OF RELATED LITERATURE

The Development of Learning Styles Theory

The concept of learning styles originated early in the twentieth century in the discipline of psychology as an extension of the study of personality differences. Beginning with Carl Jung in 1921, psychologists have grouped individuals into different psychological types based on their emotional and behavioral responses to certain situations. Following Jung's theory of psychological type, several American psychologists have examined the existence of different ways of thinking or different cognitive styles among individuals. Cognitive style refers to the way in which an individual prefers to receive, process, and remember incoming information (Keefe, 1987). In the mid 1970s, the complete concept of learning style began to emerge, encompassing elements of cognitive style in addition to affective and physiological learning preferences (Dunn, 1984). The variables included in the three dimensions of learning style describe consistent patterns in the way an individual perceives, interacts with, and respond to a learning environment (Kuerbis, 1988).

The emphasis on an individual's internal cognitive processing in learning style theory fits into the constructivists' view of learning.
In contrast to the behaviorist tradition of B.F. Skinner and to Piaget's theory of developmental stages of learners, the learning style approach is based on cognitive science theory which suggests that knowledge of a student's cognitive processes is essential in order to understand the learning process and to improve instruction (Champagne, Klopfer, & Gunstone, 1982).

In recent years, numerous models of learning style have been developed which include a range of cognitive process variables such as analytic, spatial, discrimination, sequential processing, simultaneous processing, categorization, and memory skills (Keefe, 1988). Presently, there is no universally accepted definition of learning style, so different models include different lists of factors as learning style variables. The importance of any of these models depends upon whether their application is instrumental in making schooling more effective. Each model is associated with an instrument designed to measure individual differences with respect to variables contained in the model. Educational researchers have used these various assessment instruments to evaluate the learning styles of a wide variety of students in a number of different educational settings, and to determine whether achievement levels can be improved by providing instruction which matches a student's learning style profile.

In the area of science education, learning styles research may be instrumental in reducing the scientific literacy problem by indicating ways to help students succeed in science classes. A recent
evaluation of the learning styles of biology non-majors at Ohio State University (Melear, 1989) indicated a link between the cognitive process variables spatial and analytic skills and course performance. Other learning style variables were not significantly related to achievement. This finding supports the need for further evaluation of the nature of the spatial and analytic components of learning style and their role in learning science content with the ultimate goal of producing higher levels of achievement and more positive attitudes toward science.

Research Involving the Analytic Component of Learning Style

A great deal of what is presently known about cognitive processes is due to the extensive research efforts of Herman A. Witkin (Claxton & Murrell, 1987). Witkin focused specifically on the cognitive process of receiving information, identifying individuals as either field dependent or field independent. Witkin defined field independent individuals as those who are able to perceive individual parts of a field as distinct from the background or context and field dependent individuals as those whose perception of individual elements is strongly influenced by the surrounding field (Witkin et al., 1954). The field dependence-independence construct has also been labeled as analytic ability (Keefe & Monk, 1986). Studies of this construct in academic settings have demonstrated significant differences between field dependent and independent students with respect to course selection and career choice. Field independent
students tend to select majors such as science, engineering and mathematics which emphasize analytic skill, while field dependent students are more attracted to disciplines in the social sciences. Similarly, among elementary and secondary school teachers, those with specialties in science or mathematics are more likely to be field independent, while those with a social sciences emphasis are more likely to be field dependent (Witkin, 1976).

Other studies conducted by Witkin have shown that when students and teachers are matched in terms of field dependence and independence, students feel more positively about teachers and teachers report higher ability levels among their students (Witkin, 1976). With respect to achievement levels, however, the little research that has been done presents contradictory findings. This may be a consequence of using a model with only two dimensions that actually represent opposite poles on a continuum. In other words, there are not two distinct classes of people with respect to this aspect of cognitive style. Instead, people's perceptual orientations can be described as falling on one side of the population mean for a particular instrument.

An example of a matching study which demonstrated positive effects on achievement is provided by Douglass (1979) who found that when high school biology students received instruction using materials structured toward their cognitive style, either field dependent or field independent, they were more academically successful in learning biology. Douglass administered to 627
students a battery of tests including the Group Embedded Figures Test, a commonly used measure of field dependence versus independence, and a test of biology knowledge. Students were randomly placed into one of two treatment groups. All students received instruction by the audiotutorial method to control for teacher differences. One group used inductively designed materials while another group used deductively designed materials. Scores on posttests of content knowledge showed that field independent students from the inductive group performed significantly better than field independent students who received deductively-oriented instruction. Moreover, the deductively or globally structured materials enhanced the performance of the field dependent students significantly more than did the inductively-oriented materials. The teaching materials contained the same content, and evaluation materials for the groups were identical. Thus, changes in the sequencing of instruction altered student performance depending on the student's cognitive style.

The field dependence/independence construct was also examined, by Tanenbaum (1981), in conjunction with high and low structure materials. Tanenbaum designed high-structure materials which presented information in a logical order using a deductive sequence and low structure materials which presented identical information in a random order sequenced inductively. Tanenbaum found that field dependent students achieved significantly higher content knowledge scores using the high structure materials, and
field independent students performed significantly better after using low structure materials.

Though many studies have demonstrated that matching instruction or study practices to one's field dependence-independence preference produces positive effects on achievement and attitudes, there have also been studies reporting no significant difference between matched and mismatched groups. One example, a matching study by Macneil (1980), did not demonstrate a significant treatment-cognitive style interaction. Macneil used the Group Embedded Figures Test (GEFT) to evaluate 72 college students with respect to the field dependence-independence construct. Based on the results of the GEFT, 32 field dependent and 32 field independent students were selected as subjects for the study. Students were randomly assigned to receive either expository or discovery instruction on the topic of behavior modification. Expository instruction emphasized lecture, a high degree of structure, and logical organization of content, while discovery instruction was characterized by a low degree of teacher guidance and an emphasis on student-centered presentations of the content. A control group, which received no instruction on the topic, was also included. All subjects were given a test of content knowledge upon completion of the unit of instruction. An analysis of variance did not reveal a significant interaction between instructional style and cognitive style providing no evidence to support the matching theory.
One possible reason for conflicting research results is that consistent definitions and evaluation instruments have not been used. Conflicting results may also be due to the interference of other variables such as the nature of the content, the relationship between teacher and students, prior knowledge and experiences, or other local conditions (Doyle & Rutherford, 1984). There is also some disagreement as to whether tests of disembedding ability, which are typically used as measures of an individual's field dependence-independence preference, are valid measures of the construct (Linn & Kyllonen, 1981). Witkin originally described the construct as a personality trait rather than an ability measure (Witkin et al., 1954) and employed tests such as the rod-and-frame test (RFT) and the body-adjustment test (BAT) as measures of field dependence or independence (Witkin, 1976). These tasks evaluate whether an individual's perception of the upright is determined primarily by internal body cues or by visual cues, that is, whether they are field independent or dependent. Later, when high correlations were noted between the RFT, BAT, and tests of disembedding ability, Witkin concluded that disembedding tasks were also measures of the field dependence-independence construct. However, performance tests, such as tests of disembedding ability, are often correlated with general reasoning ability (Linn & Kyllonen, 1981) making them suspect as measures of personality. High correlations between disembedding tasks and measures of general ability led Witkin, Moore, Goodenough, Cox (1977) to suggest that the field dependence-
independence construct is actually two constructs; perception of the upright, measured by instruments like the RFT and BAT, and cognitive restructuring ability, measured by disembedding tasks. The ability to disembed simple forms from more complex figures has also been referred to as analytic ability (Keefe & Monk, 1976).

In addition to correlations with general reasoning ability, positive correlations of cognitive restructuring or analytic ability with spatial skill have frequently been reported (Vernon, 1972). For example, in an analysis of data from 34 cognitive reference tests, Linn and Kyllonen (1981) observed that commonly cited measures of spatial ability were associated with measures of cognitive restructuring or analytic ability. Linn and Kyllonen (1981) concluded that the cognitive restructuring construct actually encompasses spatial skill. Other researchers (Guay, McDaniel, & Angelo, 1978) maintain that analytic ability refers to cognitive processes separate from spatial skill. Further research is needed to clarify the relationship between these cognitive variables before conclusions as to their role in particular learning tasks can be established.

Research Specific to the Spatial Component of Learning Style

Spatial skill refers to a cognitive process variable often included in descriptions of learning style. Factor analytic studies of spatial skill have consistently demonstrated the existence of two distinct spatial skills: orientation and visualization (McGee, 1979).
Spatial orientation involves encoding and remembering a visually presented pattern so that a change in the orientation of the pattern is not confusing. Spatial visualization refers to the ability to mentally rotate a visual stimulus in space (McGee, 1979). Tests for both factors require the use of short-term visual memory. Spatial orientation tests typically require individuals to perceive a figure as a whole and mentally rotate the figure in order to determine whether it is the same as or different from another group of figures (Elkstrom, French, & Harman, 1976). In other words, orientation tests measure the ability to recognize the same figure from different angles. Measures of spatial visualization differ from orientation tasks in that they require the mental manipulation of visual images in three dimensions (Guay, 1980). Typical measures of this factor include the Paper Folding Test (Elkstrom, French, & Harman, 1976) and the Mental Rotations Test (Vandenbergh & Kuse, 1978).

Since both components of the spatial construct refer to skills rather than personality traits or learning preferences, the idea of providing instruction which matches a student's learning style in terms of spatial skill is somewhat inappropriate and has not been a focus of research efforts. Instead, research has been directed toward uncovering specific content areas which require high spatial skill and determining whether instructional strategies exist which enable individuals to improve their level of facility in spatial reasoning tasks.
Research has suggested that well developed spatial skill is one factor involved in the selection of science as a career choice. Exceptionally high levels of spatial skill have been reported among successful scientists (Pallrand & Seeber, 1984). Additionally, a number of researchers have reported significantly higher levels of spatial skill for college science majors when compared with other undergraduate groups. For example, Siemankowski and MacKnight (1971) found that college science majors (physics, biology, chemistry, and geoscience) scored higher on Miller's Survey of Visualization than did liberal arts majors. Baker (1983) compared the performance of physical science majors, biological science majors, and nonscience majors on the Cube Comparisons Test (Elkstrom, French, & Harman, 1976), a test of spatial orientation, and also reported that both groups of science majors scored significantly higher than did nonscience majors. Additionally, Lord (1987a) administered tests of spatial orientation, spatial visualization, and analytic ability to undergraduates and found higher levels of both components of spatial skill as well as analytic ability among biology majors when compared with liberal arts majors. Lord's findings are supported by those of Macnab and Johnstone (1990) who administered three tests of spatial ability to groups of postgraduate biologists, biology undergraduates, postgraduate nonscientists, and undergraduate nonscience majors. The three tests required subjects to visualize a two-dimensional section taken from a cut surface of a three-dimensional diagram, to visualize a three-dimensional object.
from a two-dimensional section, and to recognize an object from an altered orientation. On all tests, the order of performance level from highest to lowest (as indicated by group mean) was postgraduate biologists, biology majors, postgraduate nonscientists, and nonscience undergraduates. Findings such as these suggest that spatial skill plays an important role in choosing a scientific discipline as a career.

Due to the nature of science content and science instruction, it is not surprising that scientific disciplines are avoided by individuals with less developed spatial skills. In biology, for example, students are often expected to interpret two-dimensional sections of three-dimensional structures (Bishop, 1978), a task similar to tests of spatial visualization. Chemistry instruction frequently involves the use of two-dimensional representations of three-dimensional molecules which students are required to mentally manipulate (Pribyl & Bodner, 1987). Almost all science instruction includes the use of diagrams, charts, and graphs which students with low spatial skills often find difficult to interpret (Lord, 1987b).

In addition to the selection of science as a career choice, research has also linked spatial skill to achievement in science. For example, a 1986 study by Bodner and MacMillen indicated that spatial skill is linked to chemistry achievement. The researchers administered the Purdue Visualization of Rotations Test (ROT), the Find-A-Shape-Puzzle (a disembedding test), the Embedded Figures Test, and the Successive Figures Test to a sample of 587 college students enrolled in a general chemistry course for science and
engineering majors. Scores on the four tests were combined to yield a total spatial score which was then compared with students' performance on four chemistry achievement measures. These measures included nine multiple-choice stoichiometry questions (subscore 1), nine multiple-choice questions on the structure of metallic and ionic solids (subscore 2), an eight-part free-response quiz on the structure of crystals (subscore 3), and a 40-item, multiple-choice comprehensive exam (subscore 4). For all four chemistry subscores Pearson product-moment correlations with total spatial score were statistically significant at the .0001 level. Correlations with total spatial score among the four chemistry subscores did not differ significantly from one another regardless of the fact that two of the subscores (2 and 3) dealt with concepts that are highly spatial in nature. The researchers concluded that spatial skill plays a role in problem solving in general and not just the solving of problems involving spatial content. They suggested that spatial skill is related to the initial step of problem solving in which relevant information is disembodied from the problem and restructured into a problem the individual understands.

The findings of Bodner and McMillen (1986) are supported by a similar study conducted by Carter, LaRussa, and Bodner (1987). In this study, the ROT and Find-A-Shape-Puzzle (FASP) were completed by 850 subjects enrolled in a general chemistry course for agriculture and health science majors and 1648 subjects enrolled in a chemistry course for science and engineering majors. Scores on the
two instruments were combined to yield a total spatial score which was then used to classify subjects as having high, medium, or low spatial skill level. Chemistry achievement was measured using the multiple-choice midterm and final exams for each course. Additionally, achievement subscores were created by grouping questions of similar content from one or more of the exams. Analysis of variance results indicated that high spatial ability students outperformed low spatial ability students on all of the exams and on 26 of the 35 achievement subscores. Additionally, Pearson product-moment correlations between total spatial score and the achievement measures were statistically significant for all of the exams and for 31 of the 35 achievement subscores. Correlations were found to be highest for subscores involving problem solving skills rather than rote memorization or the application of algorithms supporting the assertion of Bodner and MacMillen (1986) that spatial skill is an important component of problem solving ability.

Pribyl and Bodner (1987) also reported significant correlations between ROT and FASP scores and chemistry exam scores among students in four organic chemistry classes. The correlations suggested that up to 15% of the variance in chemistry exam scores could be explained by spatial ability. Exam questions from one of the classes were further divided into subscores based on the type of task required in the item. As in the Carter, LaRussa, and Bodner (1987) study, correlations with total spatial score were highest for exam questions requiring either mental manipulations of figural
representations or problem solving skills. Correlations were not significant for questions requiring rote memorization or the application of algorithms.

Similarly, Staver and Jacks (1988) found spatial skill to have a significant impact on the ability of chemistry students to complete a particular type of problem solving task, namely balancing chemical equations. A group of 83 high school chemistry students completed the ROT, the FASP, and the Test of Logical Thinking (a measure of Piagetian cognitive level), as well as pre and posttests composed entirely of equation-balancing tasks. Substantial correlations among the ROT, the FASP, and the Test of Logical Thinking (TOLT) led the researchers to collapse the three independent variables into a single variable which they referred to as restructuring ability. When a hierarchical regression analysis was performed, the collapsed variable was found to significantly (p<.05) influence students' overall performance on the equation-balancing tasks.

Well developed spatial skill has also been linked to success in the biological sciences. For example, Melear (1989) reported that spatial skill was the only one of twenty-three subscales on the Learning Style Profile that was significantly (p<.0001) correlated with biology achievement in a sample of 673 non-biology majors. Other subscales, including analytic ability and memory, were not found to be significantly related to biology achievement.

A study by Lord (1987b) also indicated that spatial skill is an important correlate of success in the area of life science. A group of
undergraduate biology students completed the Cube Comparisons Test, the Paper Folding Test, and the Hidden Figures Test. Based on performance on the three tests, subjects were divided into three groups; low, medium, and high spatial ability. At the conclusion of the semester, all students completed a written final exam and a laboratory practical. On both achievement measures the order of performance of the three groups from highest to lowest mean score was high spatial ability, medium spatial ability, and low spatial ability, indicating that individuals with more highly developed visualization and orientation abilities are more likely to be successful in biology courses.

The findings of Costello (1985) also suggest a relationship between spatial skill and ability to comprehend particular biological concepts. The researcher administered a series of cognitive tests, including several measures of spatial skill, plus a 20-item test of genetics concepts to 21 students enrolled in an undergraduate genetics course. A factor analysis of total scores on the cognitive tests and individual item scores from the genetics test indicated four factors. Variables having substantial loadings on factor 1 included scores on the Paper Folding Test and the Surface Developments Test (both measures of spatial visualization) in addition to five genetics test items concerning a dihybrid cross, meiosis, the Hardy-Weinberg theorem, the numerical relationship between peptide bonds and amino acids, and the numerical relationship between nitrogenous bases and number of amino acids. Factor 4 variables included
Hidden Patterns Test score and scores on the map units items from the genetics test. These findings suggest that the type of spatial skill required varies depending on the learning task.

Some researchers have argued that spatial ability is an innate aptitude that cannot be taught (Smith, 1964; Witkin, 1969). There is evidence from research, however, that spatial reasoning is actually a skill that can be enhanced through instructional interventions and practice. For example, Pallrand and Seeber (1984) found significant gains in spatial ability among college level physics students following eleven hours of instruction specific to spatial reasoning. The experimental intervention consisted of three types of activities. One activity required subjects to practice drawing scenes as viewed through a square opening in a piece of cardboard. A second type of intervention consisted of geometry instruction focusing on planes, solid figures, and geometric transformations. The third type of activity asked students to locate the positions of objects as seen by an imaginary observer with an orientation different from their own. A comparison of pre and posttest scores on a battery of spatial orientation and visualization measures revealed gains which were significant at the .001 level for five instruments and at the .01 level for the remaining two measures. The researchers also reported significant improvements in spatial skill level in two additional groups of subjects which received physics instruction equivalent to the experimental group, but did not complete the spatial intervention sessions. This finding suggests that completing a college physics
course may itself lead to gains in spatial skill. Gains in spatial skill were highest, however, for the group which had received the special spatial skill training.

As in the Pallrand and Seeber (1984) study, Talley (1973) found significant gains in spatial skill level among college chemistry students following a spatial intervention program. The intervention program involved the use of three-dimensional models to teach chemistry concepts such as the amphoteric characteristic of water. Models were constructed by the instructor as the concepts were presented then students were asked to construct their own models using individual molecular model kits. At the end of the semester, significant gains were noted for the experimental group on two measures of spatial visualization. A control group which covered the same concepts but did not use the model kits showed a slight decrease in spatial visualization ability from pre to posttest.

Similarly, Lord (1985, 1987a) found significant gains in both spatial orientation and spatial visualization in undergraduate biology students following twelve 30-minute intervention sessions. During these sessions, students practiced mentally bisecting three-dimensional figures and drawing their perceptions of the resulting two-dimensional surfaces. Posttest scores at the end of the semester indicated significant performance improvements on the intervention task as well as on several commonly used measures of spatial orientation and visualization. No significant improvements were
noted for control groups which received equivalent biology instruction but did not complete the twelve intervention sessions.

In addition to improving spatial skill, spatial visualization training has also been shown to improve academic performance in scientific disciplines. For example, Small and Morton (1983) separated a group of 67 organic chemistry students into two groups, one of which received spatial visualization training. The training consisted of workbook exercises which included drawing two-dimensional models, constructing and rotating three-dimensional models using molecular model kits, and imagining the manipulation of three-dimensional models. The other group of students was given a workbook which contained written exercises on nomenclature, basic chemical notation, aromaticity, and resonance. A group of spatial skill pretests indicated that the two groups were matched with respect to spatial skill prior to the training exercises. A comparison of scores on the first exam did not indicate a significant difference between the two groups. However, when exam questions were sorted based on whether they required the use of stereotaxic models or were nonspatial in nature, the training group demonstrated significantly (p<0.05) higher scores on the spatial questions. Additionally, the average final exam grade for the training group was almost 12% higher than that of the control group, suggesting that spatial visualization training can improve overall course grades in organic chemistry courses. The results also suggest that performance in future courses may be improved since the final
exam was administered seven weeks after the completion of the spatial training.

Pallrand and Seeber (1984) also reported significant gains in achievement resulting from spatial instruction in a group of undergraduate physics students. The students were distributed among three treatments; experimental, placebo, and control. The experimental group received 11 hours of spatial visualization training in addition to the regular classes and lab sessions. The placebo group received equivalent physics instruction along with 11 hours of lectures on the history of physics. The control group received no instruction other than the regularly scheduled classes and lab sessions. Overall course grade for the three groups was based on a single final exam and a laboratory grade. Analysis of variance results indicated significant (p<.05) differences between the three groups with respect to lab grade and overall course grade with the experimental group outperforming the placebo and control groups. No significant difference was noted for the total final exam score. However, when exam items were divided into two subscores based on whether they involved spatial ability (such as items utilizing graphical representations) or information recall, a significant (p<.05) difference was evident between the groups with the experimental group outperforming the other groups on the spatial items. The authors suggested that spatial visualization training is important in scientific disciplines because it impacts a student's
ability to extract relevant information and organize it to solve a problem--a skill that is especially important in laboratory settings.

Talley (1973) also reported gains in achievement among undergraduate chemistry students as a result of a spatial intervention program. Analysis of variance results revealed that overall scores on seven out of seven unit exams were significantly (p<.0001) higher for subjects who participated in the intervention program than for control group subjects, with a trend toward increasing F ratios as the semester progressed. Each exam was composed of 15 analogy items, 10 knowledge items, 10 comprehension items, 5 application items, 5 analysis items, and 5 evaluation items. All items, with the exception of the analogy items, were classified according to Bloom's taxonomy. Analysis of variance results by item type revealed that scores on the knowledge level items for the control group were significantly higher than those of the experimental group. No significant differences were noted between the two groups on the comprehension level items. However, highly significant differences in favor of the experimental group were reported for the analogy, application, analysis, and evaluation items, with F ratios increasing steeply as the semester progressed. The author concluded that individuals with more highly developed visualization skills have enhanced capabilities to perform at higher cognitive levels while individuals with less developed spatial abilities function predominantly at the lower levels of knowledge and comprehension.
Despite findings from a number of studies linking commonly used measures of spatial ability with science achievement, there is still some question as to the exact relationship between science achievement and spatial skill due to concerns about the construct validity of many spatial skill assessment measures. For example, Spearman and Jones (1950) suggested that some of the tests designed to measure visuospatial aptitude actually measure a factor that is inseparable from verbal ability and general reasoning skills. They noted that many of the items on tests of spatial skill could:

be readily solved in two distinct manners. One may be called analytic, in the sense that attention wanders from one element of the figure to another. The other mode of operation is comparatively synthetic, in that the figures (or their constituents) are mentally grasped in much larger units (sometimes called "wholes"). (p. 70)

They further explained that the analytic problem solving strategy tends to group with Spearman's (1927) General Intelligence Factor (g). The conclusions of Spearman and Jones (1950) are supported by Smith (1964) and Vandenberg (1975) who presented evidence that many of the items on spatial tests can be solved using a minimal amount of the synthetic or gestalt processing that is characteristic of true spatial tasks. Instead, these items can be solved using analytic strategies which involve trial-and-error comparisons of relationships between different parts of a figure.

Additionally, Guay (1980) suggested that many tests commonly cited as measures of spatial ability contain items which can be solved using several different cognitive processing strategies so that these
tests may actually be measuring different abilities for different individuals depending on which strategy they employ. In agreement with findings from previous research, Guay, McDaniel, and Angelo (1978) found analytic processing to be a confounding factor in many spatial skill assessment measures. The researchers reviewed 31 commonly used spatial tests and selected the five instruments they found to be least confounded and the four instruments they found to be most confounded by analytic processing. Sixteen subjects were then asked to complete representative items from the nine tests and verbally explain their thought processes as they completed each item. Four judges rated subjects' responses on a scale of one to six with one indicating highly analytic processing and six indicating highly synthetic or gestalt processing. The results suggested that none of the tests was an entirely pure measure of spatial skill. Additionally, the degree of analytic processing elicited by a particular item varied among subjects so that none of the items consistently measured the same cognitive process variable in all subjects.

Similarly, Kyllonen, Lohman, and Snow (1984) found that subjects often alternated between spatial and analytic strategies within the same instrument. Specifically, the researchers reported that subjects shifted between analytic and spatial strategies on the Paper Folding Test depending on the number of folds, the number of hidden folds, and the symmetry of the folds on a particular item. On easier items subjects generally reported using analytic strategies, but
on more difficult items most subjects reported the need to mentally visualize the folding and unfolding of the piece of paper.

Analytic confounding of the Paper Folding Test is also suggested by Linn and Kyllonen's (1981) finding that the Paper Folding Test correlated highly with cognitive restructuring or analytic processing tests including the Hidden Figures Test. Additionally, Zimowski and Wothke (1988) reported that 50% of the true score variance in Paper Folding Test scores in a sample of 1718 adults was attributable to nonspatial sources while only 27% was attributable to holistic processing or spatial ability.

In a study of 31 widely used spatial tests, Guay, McDaniel, and Angelo (1978) found the ROT and the Mental Rotations Test to be least confounded by analytic processing. Several of the studies (Bodner & McMillen, 1986; Carter, LaRussa, & Bodner, 1987; Pribyl & Bodner, 1987) in which significant correlations between spatial skill and science achievement were reported employed the ROT as a measure of spatial skill suggesting that analytic confounding was not present in these studies. However, each of these studies also included scores on tests of disembedding or analytic ability as part of an individual's total spatial score. Disembedding tasks do not require the mental manipulation of visual images which is characteristic of valid measures of spatial skill (Guay, 1980). The situation is further complicated by Bodner and McMillen's (1986) finding that scores on disembedding tests were significantly correlated with scores on the ROT, a test of spatial skill which has been shown to be least
confounded by analytic processing (Guay, McDaniel, & Angelo, 1978). This finding raises the question as to whether spatial skill and analytic skill are actually separable constructs.

In the area of biology, the findings of Russell-Gebbett (1984, 1985) point strongly to the existence of two discrete cognitive skills which are both necessary in order for students to successfully interpret three-dimensional biological structures and specimens. A cluster analysis of test scores and individual interviews consistently demonstrated that students employ two separate skills when attempting to answer problems involving three-dimensional structures. One skill, referred to by the researcher as the abstraction of sectional shapes, corresponds to spatial visualization ability in that it involves wholistic processing. According to the author, this skill involves the formation and retention of mental images so that a particular shape can be identified from a series of shapes or reconstructed on paper. The other skill is described by the researcher as "an appreciation of the spatial relationships of internal parts of a three-dimensional structure seen in differing sectional planes" (Russell-Gebbett, 1985, p. 293). This definition corresponds to analytic processing in that trial-and-error comparisons of relationships between different parts of a figure are made. The researcher reported that some students are able to employ both skills when attempting to solve biology problems involving three-dimensional structures while other students display a distinct strength and/or weakness for one of the skills which impacts their
ability to comprehend particular structures. This finding indicates a need to identify factor-pure measures of the two skills in order to diagnose potential areas of weakness so that remediation can be provided prior to or concurrently with instruction.

Overall, there is evidence from past research that spatial skill plays a key role in understanding many scientific concepts. Research suggests that spatial skill assessment measures may be useful as a means of identifying students who are at risk of poor performance in science courses. Research also suggests that, once such students are identified, intervention methods may be effective with respect to both increasing levels of spatial skill and improving performance in science classes. Further research is needed, however, to clarify whether it is actually spatial skill, analytic skill, or both cognitive process skills that are important in science achievement. Further research is also warranted to identify the specific scientific concepts and processes which require spatial and/or analytic ability. Additionally, further research is needed to identify the instructional interventions which are most effective in improving students' spatial and/or analytic skills and helping students achieve success in science courses.
Design

To further examine the relationships between spatial ability, analytic ability, and biology achievement in non-majors, five different spatial and/or analytic instruments were administered to a group of undergraduates enrolled in Biology 101, a biology course for non-majors at a large, midwestern university. Biology 101 is a new general biology course for non-majors designed to replace both the audio-tutorial course (Biology 110) and the previous two quarter traditional sequence (Biology 107 and 108). Biology 101 was designed to differ from the previous non-majors courses by focusing on the social responsibility and personal relevance associated with biological concepts. It is anticipated that 1500-1800 students will enroll in the course each quarter. During the quarter in which the present research was conducted, the final enrollment for the course was 1146 students.

The format of Biology 101 is such that all students attend three hours of lecture per week, one hour of recitation, and two hours of lab. Lectures are given in three sections by three different instructors. Students in a particular section receive all of their
lectures from the same instructor. The same text is required for all three lecture sections, but the content of the lectures differs according to the preferences of the instructor. Laboratory activities and weekly recitation are completed in smaller sections of not more than 24 students each. Laboratory and recitation sections are led by graduate teaching associates. All students complete the same nine laboratory sessions using the same laboratory manual. There is also some uniformity across recitation sections due to printed guidelines which are discussed in a weekly meeting required of all graduate teaching associates.

Course grades for Biology 101 are determined based on a curve derived from the overall distribution of total points for each lecture section. There are 500 possible points consisting of two 100-point midterms, one 200-point final, one 50-point laboratory report, and 50 potential bonus points. Both of the midterms and the final exam are multiple choice in format and computer scored. The lecturers each construct their own exams so there are three different forms of each midterm and the final exam. Exam questions cover both lecture and laboratory topics. Bonus points can be earned by completing assignments based on the General Biology Department's in-house newsletter, *The Life Times*. The newsletter is basically a compilation of shortened forms of research reports and magazine articles dealing with current happenings and topics of interest in biology. Assignments include brief quizzes, worksheets, and reaction papers.
During the quarter in which the present research was conducted, students could also earn ten bonus points by completing the five spatial and/or analytic instruments. Students were given their choice of four test sessions which met at times other than the regularly scheduled lectures, laboratories, and recitation sections. In addition to the ten bonus points, students who participated in the study also received a written report summarizing their performance on the spatial/analytic instruments as compared to the group performance.

Subjects

The subjects of the study included 728 volunteers from among the students enrolled in Biology 101 during Autumn Quarter of 1990. Of the 728 volunteers, 278 (38.2%) were enrolled in lecture section A, 218 (29.9%) were enrolled in lecture section B, and 232 (31.9%) were enrolled in lecture section C. Based on total enrollment for the course, 37.3% of Biology 101 students attended lecture section A, 25.6% attended lecture section B, and 37.1% attended lecture section C.

The mean score on the final examination for the 728 subjects of the study was 72.0%. The average final exam score for the Biology 101 students who elected not to complete the spatial skill assessments was 69.0%. Since the material covered in each lecture section differed according to the particular interests and preferences of the three lecturers, each lecture section completed a different final
exam developed by the section's instructor. For lecture section A, the mean score on the final exam was 73.2% for study participants and 68.8% for non-participants. For lecture section B, the mean final exam score for volunteers was 73.7% while non-volunteers scored an average of 69.8%. Volunteers from lecture section C averaged 68.8% on the final exam while non-volunteers scores averaged 68.4%.

Across all lecture sections a greater percentage of the 728 volunteers were females than males. Within the total course enrollment, 57.9% of the students were women. Overall, 63.3% of the 728 volunteers were females while only 48.6% of the students who did not volunteer were female. When the subjects are considered by lecture section, 66.2% of the volunteers from lecture section A were women (as compared to 50.7% female non-volunteers), 54.6% of the volunteers from lecture section B were women (as compared to 42.7% non-volunteers), and 68.1% of the subjects from lecture section C were women (as compared to 49.2% female non-volunteers).

Instrumentation

Five measures of spatial and/or analytic ability were used in the study: The Purdue Visualization of Rotations Test (Guay, 1980), the Mental Rotations Test (Vandenberg & Kuse, 1978), the Hidden Figures Test (Elkstrom, French, & Harman, 1976), the Card Rotations Test (Elkstrom, French, & Harman, 1976), and the Paper Folding Test (Elkstrom, French, & Harman, 1976). The Purdue Visualization of Rotations Test and the Mental Rotations Test were chosen because
they have been shown to be spatial visualization measures least confounded by analytic processing when compared with other purported measures of spatial ability (Guay, McDaniel, & Angelo, 1978).

The Purdue Visualization of Rotations Test (ROT) contains 30 items which require an individual to mentally manipulate a three-dimensional figure in the same manner as a reference figure (Guay, 1980). Items gradually increase in difficulty as the degree of rotation of the reference figure is increased and the number of axes on which the figure is rotated increases from one to two. For all 30 items the reference figure is the same. The object which the individual must manipulate is different for each item and can be described as either a truncated hexahedron, a right circular cylinder, a right rectangular prism, or a right triangular prism. A sample item from the ROT is provided in Figure 1. When the entire test is administered, subjects are given 20 minutes to complete the 30 items. The test was designed for use with populations of age 13 or older.

Guay (1980) and Guay and McDaniel (1978) reported reliability coefficients (KR-20) for the ROT in samples of college students of .87 and .92, respectively. Carter, LaRussa, and Bodner (1987) reported split-half reliability coefficients of .80 and .82 for a shortened version of the ROT administered to undergraduates. In a pilot study (Sutherland, 1990) for the present research, a reliability coefficient (Cronbach’s α) of .84 was found for the entire ROT in a sample (n=51)
of undergraduates enrolled in a biology course for non-majors. Some evidence of construct validity for the ROT was provided in the Guay, McDaniel, and Angelo (1978) study. Through the analysis of self-reports of the strategies employed to answer the ROT items the researchers concluded that the ROT tasks require spatial processing rather than analytic processing.

The Mental Rotations Test (MRT) is a 20 item test which also requires the mental manipulation of a three-dimensional figure (Vandenberg and Kuse, 1978). Each item consists of a reference figure followed by four additional figures. Two of these figures are considered to be correct and are identical in shape to the reference figure, but have been rotated about the vertical axis. The other two figures are incorrect or "distractors" and are either rotated mirror images of the reference figure or rotated images of reference figures from other items. A sample of each type of item is provided in Figure 2. Subjects are allowed six minutes to complete the 20 items.

Vandenberg and Kuse (1978) reported a KR-20 of .88 for the MRT in a group of 3268 adults and adolescents age 14 and older. Following an interval of one year a test-retest reliability of .83 was reported for a sample of 336 subjects. Preliminary research (Sutherland, 1990) for the present study demonstrated a reliability coefficient (Cronbach's α) of .76 for the MRT in a sample of 51 undergraduates enrolled in a non-majors biology course. Evidence for the construct validity of the MRT is provided by the Guay and McDaniel (1978) study in which a correlation of .61 was observed
between MRT and ROT scores. Evidence of construct validity is also provided by Vandenberg and Kuse (1978) who reported correlation coefficients suggesting an association between the MRT and a number of other measures of spatial visualization.

The Hidden Figures Test (HFT), along with the two remaining instruments, is part of The Kit of Factor-Referenced Cognitive Tests (Elkstrom, French, & Harman, 1976) published by the Educational Testing Service. The HFT is listed as a measure of a cognitive factor called flexibility of closure (Elkstrom, French, & Harman, 1976). The test was selected because it requires subjects to locate one of five simple geometric figures embedded in a more complex figure. This type of disembedding task has generally been associated with Witkin's field dependence-independence construct which is also referred to as analytic skill (Keefe & Monk, 1986) or the ability to identify individual components of a visual field as distinct from their background. However, other researchers (Linn & Kyllonen, 1981; Bodner & McMillen, 1986; Carter, LaRussa, & Bodner, 1987) suggest that tests of disembedding ability are actually measures of spatial ability. The test developers report that the HFT has some variance on both the spatial orientation and the spatial visualization factors. Two examples of the 32 HFT items are shown in Figure 3. The test was designed for use with grades 8-16.

For the Hidden Figures Test, Educational Testing Service reports reliability coefficients of .82, .80, and .83 with .83 representing a study involving college students. Pilot research (Sutherland, 1990)
for the present project indicated a reliability coefficient (Cronbach's $\alpha$) of .85 in a sample of 51 undergraduate non-biology majors. Subjects in the pilot study reported feeling frustrated after completing the HFT, supporting the instrument developers' statement that the difficulty level of the HFT is high.

The Card Rotations Test (CRT) is also part of *The Kit of Factor-Referenced Cognitive Tests* (Elkstrom, French, & Harman, 1976). It is categorized as a test of spatial orientation ability. The Card Rotations Test was selected because it is purported to be a test of the component of spatial ability which refers to one's ability to remain unconfused by changing orientations in which visual stimuli are presented (McGee, 1979). However, the tasks required to complete the instrument can be accomplished by what Guay and McDaniel (1978) call "explicit trial and error checking of the relationships between parts of a figure." The CRT consists of 20 items which require an individual to identify whether a series of eight figures are the same as or different from a reference figure. The eight figures are actually all the same shape as the reference figure, however some of the figures have been flipped over and some have simply been rotated to a slightly different position. Subjects are to identify a figure as the same as the reference figure if rotation alone has been applied. The figure is to be labeled as different if it can not be made to look like the reference figure by rotation alone. Several sample items from the CRT are shown in Figure 4. Guay and McDaniel (1978) suggest that since such tasks do not necessitate the
mental manipulation of a figure in space they are actually measures of analytic processing rather than the Gestalt processing which they suggest is characteristic of spatial tasks.

The instrument developers report reliability coefficients of .80 and .83 for the Card Rotations Test in two studies of undergraduate students. Preliminary research (Sutherland, 1990) in a sample of 51 biology students enrolled in a course for non-majors yielded a reliability coefficient (Cronbach's \( \alpha \)) of .98. Evidence for the construct validity of the CRT is provided by the Vandenberg and Kuse (1978) study in which Pearson product-moment correlations of .62 and .58 were reported between the MRT and the Card Rotations Test in samples of 456 and 3435 subjects, respectively.

The Paper Folding Test (PFT) is categorized as a test of spatial visualization (Elkstrom, French, & Harman, 1976). It contains 20 items which depict a square piece of paper being folded in various ways in successive drawings. The final drawing in each item demonstrates the location of a hole punched in the folded piece of paper. The subject's task is to select which of five additional drawings represents the appearance of the paper after being reopened. Items differ with respect to the number of folds shown and the symmetry of the folds. An example item from the PFT is shown in Figure 5. The PFT was selected for inclusion in the study because research using this instrument suggests that subjects shift solution strategies depending on the difficulty of the item (Kyllonen, Lohman, & Snow, 1984). Items considered to be more difficult were
those containing the greatest number of folds or asymmetric folds. With respect to easy items, subjects reported using analytic processing strategies. On difficult items, however, subjects reported using mental imaging or spatial visualization strategies. The Paper Folding Test was also chosen because the spatial ability subscale of the Learning Style Profile (LSP) includes paper folding items. The preliminary research (Melear, 1989) on which the proposed research is based suggested that an individual's score on the LSP spatial subscale is significantly correlated with success in a non-majors biology course.

The Paper Folding Test was designed for use with populations ranging from grades 8-16. The Educational Testing Service reports a reliability coefficient for the PFT of .84 for a college-age sample. Research (Sutherland, 1990) using the PFT in a sample of undergraduate biology non-majors (n=51) demonstrated a reliability coefficient (Cronbach's α) of .80.

In order to minimize the effect of fatigue on performance and to accomplish the assessment of spatial and analytic skill in the time allotted by the university for a single meeting of a one hour course, only half of the items from each instrument were administered. The halves consisted of either all of the odd numbered items or all of the even numbered items from each of the five instruments. Subjects were asked to complete the items in one-half of the time recommended for use with the entire instrument.
Figure 1. Sample ROT item.
Figure 2. Sample MRT items.
Figure 3. Sample HFT items.
Figure 4. Sample CRT items.
Figure 5. Sample PFT item.
The biology achievement measure used to examine the relationship between spatial ability and performance in a non-majors biology course was the final examination for the course. Three forms of the final were developed (one by each of the three lecturers). All three exams were composed of 100 multiple choice items and were completed within a 108 minute time limit. Overall performance on the final was recorded for subjects in all three lecture sections (n=728). Additionally, individual item responses were recorded for subjects in lecture section A (n=278) so that an in-depth analysis of the relationship between spatial ability and particular biological concepts and item types could be completed. Part of the analysis involved sorting the 100 items on the lecture section A final according to the topics covered. Table 1 provides a list of lecture topics that were included in the course syllabus for lecture section A. Subscores on the final were computed for each lecture topic. Since a number of the lectures contained information that could be assigned to several topics additional subscores were computed. For example, one of the three items drawn from the DNA lecture asked students to identify the names of the scientists who first proposed the concept of the double helix. This item was included in a subscore which only contained items that required students to identify biographical information about particular scientists.

In addition to being sorted by lecture topics, the 100 items were also sorted by laboratory topic. All Biology 101 students completed the nine laboratory sessions listed in Table 2. The
laboratory activities are described in detail in a manual developed by the general biology department at the university. In addition to descriptions and instructions for the actual activities completed by the students, the manual also contains substantial sections of background text with related written exercises. Since a large portion of the information presented in the laboratory manual overlapped with the material presented in lecture, items from the final were sorted according to laboratory topic in three ways. Initially, subscores for each laboratory activity were computed using all items that matched the topic. These subscores included items that were also covered in the text of the laboratory manual, the lecture material, or the assigned readings for the lecture section. The second set of laboratory subscores included only items that referred to an actual activity completed in a laboratory session. The answers to some of these items, however, were also provided in the lecture material or in the assigned readings for the lecture section. The final set of laboratory subscores included items that were only discussed during laboratory sessions and were not included in lecture material or in supplementary readings.

The division of items based on item type included subscores for items that involved a quantitative versus a qualitative understanding and subscores for each level of Bloom's (1956) taxonomy of educational objectives addressed (i.e., knowledge, comprehension, application, analysis, and synthesis or evaluation). The researcher originally intended to sort items based on whether
they contained a chart, graph, or other type of figure. However, there were no figures of any kind in the lecture section A final.
Table 1.

**Lecture Topics for Section A.**

<table>
<thead>
<tr>
<th>Lecture</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Biology as discovery; Unifying principles of life</td>
</tr>
<tr>
<td>2</td>
<td>Diversity of life: survey of kingdoms and major phyla</td>
</tr>
<tr>
<td>3</td>
<td>Distribution of life on Earth; History of life</td>
</tr>
<tr>
<td>4</td>
<td>Prokaryotic life forms: viruses and bacteria</td>
</tr>
<tr>
<td>5</td>
<td>Origin of eukaryotic cell, General cell structure</td>
</tr>
<tr>
<td>6</td>
<td>Eukaryotic life forms, Evolution of multicellularity</td>
</tr>
<tr>
<td>7</td>
<td>Multicellular life forms: lichens and fungi, Introduction to plant kingdom</td>
</tr>
<tr>
<td>8</td>
<td>Plants: photosynthesis</td>
</tr>
<tr>
<td>9</td>
<td>The food chain</td>
</tr>
<tr>
<td>10</td>
<td>Animals: symmetry, movement, diversity, and abundance</td>
</tr>
<tr>
<td>11</td>
<td>Animals: dinosaurs, to mammals to humans</td>
</tr>
<tr>
<td>12</td>
<td>The blueprint for life: DNA</td>
</tr>
<tr>
<td>13</td>
<td>Genes and the genetic code</td>
</tr>
<tr>
<td>14</td>
<td>Reproduction I: mitosis and asexual reproduction</td>
</tr>
<tr>
<td>15</td>
<td>Reproduction II: meiosis and sexual reproduction</td>
</tr>
<tr>
<td>16</td>
<td>Life cycles: fertilization, development, and maturation</td>
</tr>
<tr>
<td>17</td>
<td>Mendelian genetics</td>
</tr>
<tr>
<td>18</td>
<td>Genes in populations; Microevolution</td>
</tr>
<tr>
<td>19</td>
<td>Darwin: evolution by natural selection, adaptation</td>
</tr>
<tr>
<td>20</td>
<td>Other forces in evolution; roles of chance and mutation</td>
</tr>
</tbody>
</table>
Table 1 (continued)

<table>
<thead>
<tr>
<th>Lecture</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>Coevolution and community interactions</td>
</tr>
<tr>
<td>22</td>
<td>Community organization and development</td>
</tr>
<tr>
<td>23</td>
<td>Biotechnology and the manipulation of life</td>
</tr>
<tr>
<td>24</td>
<td>Biotechnology and genetic engineering: possibilities, problems, and politics</td>
</tr>
<tr>
<td>25</td>
<td>Manipulation of the environment: the importance of biodiversity</td>
</tr>
<tr>
<td>26</td>
<td>The biosphere</td>
</tr>
<tr>
<td>27</td>
<td>Global effects of pollutants, The Gaia hypothesis, conservation and environmentalism</td>
</tr>
</tbody>
</table>
Table 2.

**Biology 101 Laboratory Topics.**

<table>
<thead>
<tr>
<th>Session</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Observing organismic diversity</td>
</tr>
<tr>
<td>2</td>
<td>Dissection of invertebrates</td>
</tr>
<tr>
<td>3</td>
<td>Fundamental molecular processes</td>
</tr>
<tr>
<td>4</td>
<td>Cell reproduction</td>
</tr>
<tr>
<td>5</td>
<td>Simple Mendelian inheritance</td>
</tr>
<tr>
<td>6</td>
<td>Population genetics and evolution</td>
</tr>
<tr>
<td>7</td>
<td>Ecology</td>
</tr>
<tr>
<td>8</td>
<td>Plant form, function, and reproduction</td>
</tr>
<tr>
<td>9</td>
<td>Animal behavior</td>
</tr>
</tbody>
</table>
Statistical Analysis

The SPSS-X programs operating on the main computer at Ohio State University were used for all data analysis procedures. Initially, means, standard deviations, and reliability estimates including inter-item correlations were calculated separately for each of the five spatial and/or analytic instruments. Additionally, inter-instrument correlations were calculated as possible support for construct validity and as an overview of how the spatial, analytic, or spatial and analytic instruments relate to each other.

Each of the instruments was then subjected to a factor analysis procedure to determine whether the instruments are actually measures of a single factor. Items from the individual instruments that demonstrated strong factor loadings on a single factor were examined to identify similar characteristics within the factor as well as characteristics which differed from items on the same instrument that showed strong factor loadings on other factors. To aid in evaluating any overlap among the instruments with respect to the constructs represented by the factors, a factor analysis was also computed using items from each instrument taken as a group. Additionally, the five total scores from the instruments were subjected to a factor analysis procedure.

To examine the relationship between spatial and/or analytic ability and biology achievement, correlations with biology achievement were computed for each instrument and for each of the factors obtained from the factor analysis of mixed items. For
subjects in all three lecture sections (n=728), correlation coefficients were calculated for each instrument and each factor using the composite measure of biology achievement obtained in Biology 101. For subjects in lecture section A (n=278), correlation coefficients were also computed for each instrument and factor using the topic, item type, and concept type subscores. A multiple regression analysis of achievement scores was performed using the five spatial and/or analytic scores and a total spatial score as independent variables. A multiple regression analysis of achievement scores was also performed using the factors obtained from the mixed analysis as predictor variables.

Additionally, an analysis of variance of biology achievement scores and subscores was performed using spatial skill level as a grouping variable. Subjects were divided into low, medium, and high spatial skill level based on total spatial score. Subjects who scored at least one-half standard deviation above the mean were classified as "high" spatial skill level while subjects who scored at least one-half standard deviation below the mean were classified as "low" spatial skill level.

Since discussions of spatial ability often involve discussions of gender differences (McGee, 1979), correlations between gender and the measures of spatial and/or analytic skill were also computed. Additionally, a regression analysis was performed using sex as the dependent variable and the five spatial and/or analytic skill
measures as predictor variables. A similar analysis was performed using the achievement measures as independent variables.

**Procedures**

The five spatial and/or analytic instruments were administered by the researcher during the third week of Autumn Quarter 1990. Students who completed the spatial skill assessments were given 10 bonus points toward their final course grade. To minimize the likelihood that students with poor course grades would comprise the majority of the volunteer pool, the spatial skill testing was completed prior to the first midterm before students had any knowledge of their standing in the course. Additionally, the spatial skill assessment was the first opportunity for Biology 101 students to earn bonus points.

Volunteers were given their choice of four test sessions which met during a one hour class period outside the regularly scheduled Biology 101 lecture, laboratory, and recitation periods. The instruments were administered in the same order in all sections, using the time allotments suggested by the instrument developers. Instructions for each instrument (including sample items) were presented in both written and oral forms. Subjects were instructed to indicate their selection of responses directly on their test booklets. Completion of the five instruments required approximately 45
minutes of the one hour class period. Individual item responses were then manually entered into an SPSS-X file and computer scored.

Biology achievement data were obtained from the director of general biology. The answer sheets for the final exam were optically scanned at the testing center for the university. Achievement data were then manually entered into an SPSS-X file using the printout of results provided by the testing center.
CHAPTER IV
RESULTS

Analysis of Spatial and/or Analytic Instruments

Overall descriptive statistics and reliability estimates for the five spatial and/or analytic instruments are listed in Table 3. The reliability coefficients for the PFT and the HFT are similar to those reported (Keefe and Monk, 1986) for the LSP spatial (a = .60) and analytic (a = .56) subscales. With the exception of the CRT, the reliabilities of all instruments are substantially lower than those reported in the pilot study (Sutherland, 1990). This finding is not unexpected since the instruments were administered in their entirety in the pilot study, while only one-half of the items from each instrument were included in the present study. Pearson product-moment correlations between the five measures are shown in Table 4. The correlation matrix shows that all of the instruments are significantly and positively correlated with each other at the .001 level, however, for all four of the spatial skill instruments the smallest degree of correlation is with the Hidden Figures Test. Additionally, a factor analysis of the five total scores suggests that the five instruments measure two factors. The rotated factor matrix shown in Table 5 indicates that the Visualization of Rotations Test,
the Card Rotations Test, the Mental Rotations Test, and the Paper Folding Test all load strongly on one factor while the Hidden Figures Test loads strongly on the second factor. Since this instrument was designed as a measure of analytic ability rather than spatial ability, these results suggest that spatial skill and analytic ability are actually two distinct cognitive constructs.

The results of the factor analysis of the five total scores also demonstrate that the Paper Folding Test shows a moderate loading on the second factor, analytic ability. This finding supports the assertion of Kyllonen, Lohman, and Snow (1984) that subjects shift solution strategies on the PFT from analytic processing to spatial visualization depending on the difficulty of the item.

An examination of the factor analysis results also indicates that the ROT demonstrates the strongest factor 1 loading among the five instruments and the weakest factor 2 loading. This supports the finding of Guay, McDaniel, and Angelo (1978) that the ROT is a relatively pure measure of spatial visualization ability when compared with other tests of spatial skill. Likewise, the MRT and CRT appear to be relatively pure measures of spatial skill based on the factor analysis results.

An overview of the results of the factor analyses of items from individual instruments is shown in Table 6. The findings of the factor analyses indicate that none of the five instruments measures a single cognitive factor. Three criteria were applied in determining the most appropriate factor solution for each instrument. First, the
skree method (Cattell, 1966) of plotting eigen value versus number of factors was applied to determine where the systematic influence due to number of factors ended. Second, only factors with eigen values greater than one were included in the analysis. Third, factors which did not account for at least five percent of the total variance were not considered in the analysis. Using these criteria, three factors are indicated for each of the spatial and/or analytic instruments.

For the Visualization of Rotations Test, the three factor solution sorts items based on similar characteristics. When consideration is given only to items with factor loadings greater than .50 on one factor and less than .30 on other factors, factor 1 includes items 1 and 3, factor 2 includes items 8, 11, and 15, and factor 3 includes items 7, 9, 10, and 12. For the two items included in factor 1, the reference figure has been rotated 90 degrees on a single axis so the subject must apply a single, 90 degree rotation to the stimulus figure. The mean score on the factor 1 items (.78) was greater than the mean scores on factor 2 (.52) and factor 3 (.52) items reflecting the less complex nature of the factor 1 items. Items loading on factors 2 and 3 required a minimum of 180 degrees rotation on either one or two axes. The factor 2 items are similar in that the stimulus figure can be described as a truncated hexahedron. The stimulus figure for factor 3 items can be described as either a right rectangular prism, a right triangular prism, or a right circular cylinder.
For the Mental Rotations Test, the separation of items into factors cannot be explained by similar item characteristics. The mean score on the factor 1 items (.32) was much greater than the mean score on the factor 2 items (.14) indicating that factor 2 items are more difficult than factor 1 items. However, factor 1 includes items 1, 3, and 5 while factor 2 includes the last three items on the instrument, suggesting that subjects either ran out of time and were forced to "guess" on the last three items or that subjects became fatigued or disoriented as they progressed through the test.

The separation of items into factors on the Paper Folding Test can again be interpreted in light of similar item characteristics. For example, the two items with strong factor 2 loadings and weak loadings on factors 1 and 3 both contain only symmetrical folds so that a symmetrical pattern of holes is produced when the piece of paper is unfolded. As reported by Kyllonen, Lohman, and Snow (1984), this type of item is less difficult for subjects. The mean score on factor 2 items was .91 as compared with means of .35 and .51 for factors 1 and 3, respectively. The two factor 3 items are similar in that both contain two folds. In each item, the piece of paper is folded in half then one half of the resulting paper is folded in half again using a diagonal fold. The resulting pattern of holes, therefore, is present on only one half of the unfolded piece of paper. The three factor 1 items are the most difficult with respect to number of folds, the symmetry of the folds, or the presence of "hidden" folds. One of the items contains three folds, two of which are asymmetrical. The
other two items contain only two folds, but one of the folds is an asymmetric fold such that the hole that is "punched" into the folded piece of paper actually only encounters a single thickness of the folded paper. It is during these more difficult PFT items that subjects use spatial visualization strategies, according to Kyllonen, Lohman, and Snow (1984).

With respect to the Hidden Figures Test, factors again correspond to item types. For example, in the factor 1 item the longest side of the hidden simple figure is located within the bottom side of the complex figure. For factor 2 items, one of the shorter sides of the simple figure is located within one of the outer edges of the complex figure. In factor 3 items, the simple figure touches one of the outer edges of the complex figure at a single point, but all of the sides of the simple figure are embedded within the complex figure. Based on these items descriptions one would expect that the lowest mean score would be seen on factor 3 items. However, mean scores were .13, .34, and .34 for items in factors 1, 2, and 3, respectively. One potential explanation for the lower mean on the factor 1 item is that this item (16) is the last item on the test while factor 2 items (1 and 3) and factor 3 items (2 and 4) are at the beginning of the instrument. As with the MRT, it is possible that subjects either became fatigued as they progressed through the instrument or did not have enough time to thoroughly examine later items. Other items with factor 1 loadings greater than .45 include items 10-14, supporting the hypothesis that factor 1 items may
represent items on which subjects were forced to "guess" due to fatigue or time constraints.

Factor analysis results from the Card Rotations Test again indicate that items with similar characteristics group together within factors. For the CRT, items containing the same shape or reference figure exhibited strong factor loadings on the same factor. The sorting of items into factors was not apparently based on degree of rotation of the stimulus figure from the reference figure or whether the stimulus figure had to be flipped to match the reference figure.

The separation of items into factors based on item characteristics such as the shape of the reference figure or the position of the item within the instrument rather than spatially oriented factors such as degree of rotation or dimensionality makes it difficult to assign meaning to the factors with respect to constructs they might represent such as spatial orientation, spatial visualization, or analytic ability. To aid in evaluating the nature of the constructs represented by the various factors within individual instruments, a factor analysis of mixed items (a subset of items from each instrument taken as a group) was also computed. Three items from each instrument were included in the analysis. The three items each had factor loadings greater than .50 on one of the factors computed from the original five instruments. At least two of the three factors from each instrument were represented in the analysis of mixed items. The third factor was not represented if all of the items with factor loadings greater than .50 on that factor were positioned in the
last half of the original instrument. This procedure was followed to minimize the likelihood that some of the items from different instruments would group together within a factor simply because a large number of subjects did not complete the items.

The same three criteria (the skree method, eigen values greater than one, and greater than five percent of the total variance) were applied in determining the most appropriate factor solution for the analysis of mixed items as were applied in the analysis of individual instruments. Using these criteria, four factors are indicated for the group of mixed items as shown in Table 7. When only items with factor loadings greater than .50 are considered, factor 1 (α=.49) includes three items from the Mental Rotations Test and two Paper Folding Test items. Both the Mental Rotations Test and the Paper Folding Test are considered to be measures spatial visualization ability. Factor 2 (α=.40) includes only the three items from the Card Rotations Test, a measure of the orientation component of spatial skill. Items with factor loadings greater than .50 on the third factor (α=.48) include two items from the Visualization of Rotations Test. This test was also designed to measure spatial visualization ability. The fourth factor (α=.18) consists entirely of items from the Hidden Figures Test, a test of flexibility of closure or analytic ability.

Although spatial visualization ability refers to a single construct, items from three measures of this construct separate into two factors, factors 1 and 3, in the analysis of mixed items. The
reason for this division is unclear. However, one potential explanation is that factor 3 includes less difficult spatial visualization tasks than does factor 1. The two ROT items included in factor 3 are representative of the least difficult type of item on the test, each requiring only a single, 90 degree rotation. The mean score for items included in factor 3 is .78. The two PFT items included in factor 1 contain asymmetric folds, a characteristic of more difficult PFT items. Additionally, although individual MRT items were not designed to vary with respect to difficulty, the MRT as a whole is a more difficult test of spatial visualization than the other tests used in the study, as indicated by the lower percent correct on the MRT (30%) when compared to the ROT (53%) and the PFT (55%). Overall, the mean score for the PFT and MRT items included in factor 1 is only .48. Therefore, it is possible that the separation of spatial visualization items into two factors is a function of item difficulty rather than an indication of two separate constructs.
Table 3.
Means, Standard Deviations, and Reliabilities of the Spatial/Analytic Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>N</th>
<th>Mean</th>
<th>Std.Dev.</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROT</td>
<td>728</td>
<td>8.0</td>
<td>3.1</td>
<td>.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(out of 15)</td>
<td></td>
</tr>
<tr>
<td>MRT</td>
<td>728</td>
<td>3.0</td>
<td>2.0</td>
<td>.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(out of 10)</td>
<td></td>
</tr>
<tr>
<td>PFT</td>
<td>728</td>
<td>5.5</td>
<td>1.9</td>
<td>.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(out of 10)</td>
<td></td>
</tr>
<tr>
<td>HFT</td>
<td>728</td>
<td>4.0</td>
<td>2.6</td>
<td>.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(out of 16)</td>
<td></td>
</tr>
<tr>
<td>CRT</td>
<td>728</td>
<td>37.8</td>
<td>14.5</td>
<td>.96</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(out of 80)</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>728</td>
<td>78.3</td>
<td>18.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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</table>
### Table 4

**Correlations between Spatial Instruments**

<table>
<thead>
<tr>
<th>Test</th>
<th>ROT</th>
<th>MRT</th>
<th>PFT</th>
<th>HFT</th>
<th>CRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROT</td>
<td>.38</td>
<td>.42</td>
<td>.18</td>
<td>.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(p&lt;.001)</td>
<td>(p&lt;.001)</td>
<td>(p&lt;.001)</td>
<td>(p&lt;.001)</td>
<td></td>
</tr>
<tr>
<td>MRT</td>
<td></td>
<td>.33</td>
<td>.21</td>
<td>.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(p&lt;.001)</td>
<td>(p&lt;.001)</td>
<td>(p&lt;.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PFT</td>
<td></td>
<td></td>
<td>.28</td>
<td>.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(p&lt;.001)</td>
<td>(p&lt;.001)</td>
<td></td>
</tr>
<tr>
<td>HFT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(p&lt;.001)</td>
</tr>
<tr>
<td>CRT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n=728
Table 5

Rotated Factor Matrix for Total Spatial/Analytic Scores

<table>
<thead>
<tr>
<th>Test</th>
<th>Factor Loading 1</th>
<th>Factor Loading 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROT</td>
<td>.77</td>
<td>.03</td>
</tr>
<tr>
<td>MRT</td>
<td>.73</td>
<td>.09</td>
</tr>
<tr>
<td>CRT</td>
<td>.73</td>
<td>.15</td>
</tr>
<tr>
<td>PFT</td>
<td>.63</td>
<td>.34</td>
</tr>
<tr>
<td>HFT</td>
<td>.12</td>
<td>.97</td>
</tr>
</tbody>
</table>

n=728
Table 6

Results of Factor Analysis of Five Spatial Instruments

<table>
<thead>
<tr>
<th>Test</th>
<th>Factor</th>
<th>α</th>
<th>Eigen Value</th>
<th>% of Var.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROT</td>
<td>1</td>
<td>.48</td>
<td>2.8</td>
<td>18.8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>.42</td>
<td>1.3</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>.42</td>
<td>1.1</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>(α=.68)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRT</td>
<td>1</td>
<td>.47</td>
<td>2.3</td>
<td>22.7</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>.41</td>
<td>1.4</td>
<td>14.4</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>*</td>
<td>1.0</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>(α=.60)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PFT</td>
<td>1</td>
<td>.47</td>
<td>2.2</td>
<td>22.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>.65</td>
<td>1.3</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>.42</td>
<td>1.1</td>
<td>11.2</td>
</tr>
<tr>
<td></td>
<td>(α=.58)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HFT</td>
<td>1</td>
<td>*</td>
<td>2.5</td>
<td>15.8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>.18</td>
<td>1.4</td>
<td>9.0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>.30</td>
<td>1.1</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>(α=.62)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRT</td>
<td>1</td>
<td>.97</td>
<td>20.2</td>
<td>25.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>.94</td>
<td>8.8</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>.72</td>
<td>4.6</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>(α=.96)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. * = not able to compute
Table 7

Results of Factor Analysis of Mixed Items

<table>
<thead>
<tr>
<th>Factor</th>
<th>Items</th>
<th>Eigen Value</th>
<th>% of Var.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MRT 1, 2, 3</td>
<td>2.2</td>
<td>14.6</td>
</tr>
<tr>
<td></td>
<td>PFT 3, 4</td>
<td>(α=.49)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>CRT 6, 16, 29</td>
<td>1.4</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>(α=.40)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ROT 1, 3</td>
<td>1.2</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>(α=.48)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>HFT 1, 3</td>
<td>1.1</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td>(α=.18)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Analysis of Biology Achievement Instrument**

Items on the Biology 101 final exam were sorted by topic to examine the possibility that particular concepts in biology require spatial visualization and orientation abilities. The sorting of biology items based on topic was completed for the lecture section A final examination only. The reliability of the 100-item instrument, as indicated by Cronbach's alpha, was .85 (n=278). Items were sorted into 23 topics, listed in Table 8, which correspond closely to the titles of the 27 section A lectures listed in Table 1. Reliability coefficients (Cronbach's $\alpha$) and a list of the item numbers contained in each topic subscore are also included in Table 8. The exam items themselves are included in Appendix A in the order in which they were presented on the final examination.

Since pilot research (Sutherland, 1990) indicated that spatial skill level is related to success in laboratory components of undergraduate biology courses, exam questions were also sorted based on whether they were drawn from lecture material or from information included in one of the nine Biology 101 laboratory sessions. Forty-one items referred to material that had been presented in a laboratory session, however, only nine of those items referred to material that had only been presented during a laboratory session and could not have been obtained by attending lecture or completing the required readings. A list of the nine laboratory topics and the test items associated with each is provided.
corresponding to the subscores for each laboratory topic. Cronbach's α for the subscore corresponding to the nine laboratory-only items was .31. The low reliabilities for both the lecture and the laboratory subscores suggest that the characteristics used for sorting items into subscores do not represent major factors in the cognitive processing required to complete the items.

Items within each of the nine laboratory subscores were further sorted based on whether they referred to an actual hands-on activity completed during a laboratory session or to material in the text of the lab manual. Table 10 describes subscores and associated reliability coefficients for items that subjects could relate to one of the hands-on activities completed during the quarter. Cronbach's α for the entire group of activity-related items was .59.

Subscores were also computed for items that involved a quantitative versus a qualitative understanding. Only six items (1, 7, 17, 39, 86, and 95) were included in the quantitative subscore (α=.35). The remaining 94 items (α=.84) involved a qualitative understanding of a concept.

Finally, since previous research (Bodner and McMillen, 1986; Carter, LaRussa, and Bodner, 1987; and Pribyl and Bodner, 1987) has indicated that spatial skill is particularly important in the successful completion of items requiring problem solving skills rather than rote memorization, biology achievement subscores were also computed based on a sorting of items according to the level of Bloom's (1956) taxonomy of educational objectives represented. Of the five levels
(knowledge, comprehension, application, analysis, and synthesis or evaluation), only the lowest three were represented among the biology achievement items. Table 11 provides a list of the items included in the knowledge (rote), comprehension, and application subscores.
Table 8.
**Topic Subscores from the Lecture Section A Final Examination.**

<table>
<thead>
<tr>
<th>Topic</th>
<th>α</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genetic Engineering</td>
<td>.49</td>
<td>1, 2, 4, 8, 9, 15, 18, 97, 99</td>
</tr>
<tr>
<td>General Cell Structure</td>
<td>.37</td>
<td>13, 58, 59, 96</td>
</tr>
<tr>
<td>Photosynthesis</td>
<td>.51</td>
<td>26, 60, 61, 62, 91</td>
</tr>
<tr>
<td>Plants and Plant Structures</td>
<td>.33</td>
<td>27, 43, 45, 49, 52, 53, 63, 76</td>
</tr>
<tr>
<td>Food Chains</td>
<td>.28</td>
<td>69, 98</td>
</tr>
<tr>
<td>Protein Synthesis</td>
<td>.32</td>
<td>39, 40, 41, 88, 89</td>
</tr>
<tr>
<td>Population Dynamics</td>
<td>.35</td>
<td>6, 11, 14, 22, 23, 95</td>
</tr>
<tr>
<td>History of Life</td>
<td>.00</td>
<td>86, 93</td>
</tr>
<tr>
<td>Natural Selection</td>
<td>.27</td>
<td>3, 78, 84, 87</td>
</tr>
<tr>
<td>Evolution</td>
<td>.26</td>
<td>5, 10, 66, 73, 85, 92, 94</td>
</tr>
<tr>
<td>Famous Scientists</td>
<td>.33</td>
<td>21, 55, 90</td>
</tr>
<tr>
<td>Environmental Concerns</td>
<td>.32</td>
<td>51, 75, 79, 83</td>
</tr>
<tr>
<td>Toxins/Carcinogens</td>
<td>.31</td>
<td>42, 46, 67, 77, 81, 82</td>
</tr>
<tr>
<td>Cell Reproduction</td>
<td>.28</td>
<td>7, 17, 19, 20, 32, 33, 34, 35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>74</td>
</tr>
<tr>
<td>DNA Replication</td>
<td>.03</td>
<td>31, 34, 71</td>
</tr>
<tr>
<td>Nature of Science</td>
<td>*</td>
<td>68</td>
</tr>
<tr>
<td>Metabolism</td>
<td>*</td>
<td>64</td>
</tr>
<tr>
<td>Animal Phyla</td>
<td>.28</td>
<td>29, 36, 54, 56, 65, 72, 100</td>
</tr>
<tr>
<td>Prokaryotic Life Forms</td>
<td>.28</td>
<td>48, 57</td>
</tr>
<tr>
<td>Community Interactions</td>
<td>.10</td>
<td>12, 24, 30, 47</td>
</tr>
<tr>
<td>Topic</td>
<td>$\alpha$</td>
<td>Items</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------</td>
<td>------------------</td>
</tr>
<tr>
<td>Genetics</td>
<td>.37</td>
<td>19, 25, 28, 44</td>
</tr>
<tr>
<td>Population Genetics</td>
<td>.18</td>
<td>37, 38</td>
</tr>
<tr>
<td>The Biosphere</td>
<td>.07</td>
<td>24, 50</td>
</tr>
</tbody>
</table>

Note. * = not able to compute
Table 9.  
**Laboratory Topic Subscores from the Lecture Section A Final Examination**

<table>
<thead>
<tr>
<th>Session</th>
<th>Topic</th>
<th>α</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Organismic diversity</td>
<td>.21</td>
<td>29, 36, 45*, 53*, 57, 54*, 63, 65, 100</td>
</tr>
<tr>
<td>2</td>
<td>Dissection of invertebrates</td>
<td>.08</td>
<td>54, 56*, 72</td>
</tr>
<tr>
<td>3</td>
<td>Fundamental molecular processes</td>
<td>.57</td>
<td>31, 34, 39, 40, 58</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>88, 89, 91</td>
</tr>
<tr>
<td>4</td>
<td>Cell reproduction</td>
<td>.26</td>
<td>7, 17, 19, 28, 32, 34, 35, 44, 74</td>
</tr>
<tr>
<td>5</td>
<td>Simple Mendelian inheritance</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>Population genetics &amp; evolution</td>
<td>.10</td>
<td>37, 38, 92</td>
</tr>
<tr>
<td>7</td>
<td>Ecology</td>
<td>.16</td>
<td>6, 23*, 69</td>
</tr>
<tr>
<td>8</td>
<td>Plant form &amp; function</td>
<td>.18</td>
<td>27*, 43*, 53, 63</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>76*</td>
</tr>
<tr>
<td>9</td>
<td>Animal behavior</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. *=Item drawn exclusively from laboratory material.
Table 10.  
**Hands-on Activity Subscores from the Lecture Section A Final Examination**

<table>
<thead>
<tr>
<th>Session</th>
<th>Topic</th>
<th>α</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Organismic diversity</td>
<td>.34</td>
<td>29, 36, 45, 57, 63, 65</td>
</tr>
<tr>
<td>2</td>
<td>Dissection of invertebrates</td>
<td>.08</td>
<td>54, 56, 72</td>
</tr>
<tr>
<td>3</td>
<td>Fundamental molecular processes</td>
<td>.43</td>
<td>31, 39, 40, 89</td>
</tr>
<tr>
<td>4</td>
<td>Cell reproduction</td>
<td>.09</td>
<td>7, 17, 19, 35, 44, 74</td>
</tr>
<tr>
<td>5</td>
<td>Simple Mendelian inheritance</td>
<td>*</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>Population genetics &amp; evolution</td>
<td>.18</td>
<td>37, 38</td>
</tr>
<tr>
<td>7</td>
<td>Ecology</td>
<td>.10</td>
<td>23, 69</td>
</tr>
<tr>
<td>8</td>
<td>Plant form &amp; function</td>
<td>.25</td>
<td>27, 43, 63, 76</td>
</tr>
<tr>
<td>9</td>
<td>Animal behavior</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note.  * = not able to compute
Table 11.

**Bloom's Taxonomy Subscores from the Lecture Section A Final Examination**

<table>
<thead>
<tr>
<th>Level</th>
<th>(\alpha)</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge (rote memory)</td>
<td>.80</td>
<td>1, 2, 3, 4, 5, 8, 13, 16, 18, 20, 21, 22, 24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>26, 27, 28, 31, 32, 33, 34, 36, 37, 39, 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>41, 43, 45, 48, 50, 51, 52, 53, 54, 55, 56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57, 58, 59, 61, 62, 63, 64, 65, 66, 67, 68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>69, 70, 71, 72, 74, 75, 77, 78, 79, 80, 81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>82, 83, 84, 86, 87, 88, 89, 90, 91, 92, 93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>94, 95, 96, 97, 99, 100</td>
</tr>
<tr>
<td>Comprehension</td>
<td>.58</td>
<td>6, 9, 10, 11, 12, 19, 23, 29, 30, 35, 38,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>42, 44, 46, 47, 60, 73, 76, 85, 98</td>
</tr>
<tr>
<td>Application</td>
<td>.33</td>
<td>7, 14, 17, 25, 49</td>
</tr>
</tbody>
</table>
Relationship between Spatial and/or Analytic Ability and Overall Biology Achievement

With respect to the relationship between spatial skill and biology achievement, Pearson product-moment correlations between the five total spatial and/or analytic scores and the biology final exam score indicate statistically significant relationships between the three spatial visualization measures, the analytic ability measure, and overall biology achievement. A statistically significant relationship is not indicated, however, for spatial orientation scores and overall biology achievement. Correlation coefficients and probability values for the five total spatial and/or analytic scores and the composite biology score are reported in Table 12. The spatial test that is most strongly correlated with biology achievement is the ROT, a test that has been shown (Guay, McDaniel, and Angelo, 1978) to be a relatively pure measure of spatial visualization when compared with other measures of spatial skill. Additionally, the regression analysis of biology achievement by spatial and/or analytic scores shown in Table 13 indicates that ROT score and PFT score, both measures of spatial visualization, are significant predictors of biology achievement.

A significant relationship between spatial skill and biology achievement is also indicated by the analysis of variance of achievement scores by spatial ability level shown in Table 14. When subjects are divided into high, medium, and low spatial skill level based on the sum of the five spatial and/or analytic scores, a
statistically significant difference (F=3.14, p=.044) is evident between the mean biology exam scores of the three groups. The high spatial skill level group exhibits the highest mean biology achievement score (73.1), while the low spatial skill level group exhibits the lowest mean biology achievement score (71.0). The mean achievement score for the medium spatial ability group is 71.6.

Pearson product-moment correlations between scores on the four factors established in the analysis of mixed spatial and/or analytic items and the biology final exam indicate a statistically significant relationship between Factors 1, 3, and 4, and biology achievement. Correlations between factor scores and achievement measures are reported in Table 15. As with total spatial orientation score, the spatial orientation factor (Factor 2) score is not significantly correlated with biology achievement. The strongest correlation with biology achievement is evident for Factors 1 and 3 which both contain items from tests of spatial visualization. The results of a regression analysis of biology achievement by factor scores shown in Table 16 also indicate that the spatial visualization factor scores are statistically significant predictors of biology achievement. Pearson product-moment correlations indicate that, in addition to the spatial visualization factors, the analytic ability factor, Factor 4, is also significantly correlated with biology achievement. However, despite the fact that Factors 1, 3, and 4 are significantly correlated with biology achievement, the correlation coefficients are
relatively small indicating that scores on these factors do not explain much of the total variance among biology achievement scores.
Table 12

**Correlations between Biology Exam Score and Spatial Test Scores**

<table>
<thead>
<tr>
<th>Test</th>
<th>r</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROT</td>
<td>.21</td>
<td>&lt;.000</td>
</tr>
<tr>
<td>MRT</td>
<td>.09</td>
<td>.009</td>
</tr>
<tr>
<td>PFT</td>
<td>.16</td>
<td>&lt;.000</td>
</tr>
<tr>
<td>HFT</td>
<td>.09</td>
<td>.006</td>
</tr>
<tr>
<td>CRT</td>
<td>.05</td>
<td>.094</td>
</tr>
</tbody>
</table>

n=728

Table 13

**Regression of Biology Achievement by Spatial Test Totals**

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>Mult R</th>
<th>RSQ</th>
<th>F</th>
<th>Sig F</th>
<th>Beta In</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ROT</td>
<td>.21</td>
<td>.05</td>
<td>35.0</td>
<td>&lt;.000</td>
<td>.21</td>
</tr>
<tr>
<td>2</td>
<td>PFT</td>
<td>.23</td>
<td>.05</td>
<td>20.0</td>
<td>&lt;.000</td>
<td>.09</td>
</tr>
<tr>
<td>3</td>
<td>HFT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.04</td>
</tr>
<tr>
<td>4</td>
<td>MRT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.01</td>
</tr>
<tr>
<td>5</td>
<td>CRT</td>
<td>.24</td>
<td>.06</td>
<td>1.9</td>
<td>.119</td>
<td>-.07</td>
</tr>
</tbody>
</table>

n=728
Table 14

ANOVA of Achievement Scores by Spatial Ability Level

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Ability Level</td>
<td>2</td>
<td>597.39</td>
<td>298.70</td>
<td>3.14</td>
<td>.044</td>
</tr>
<tr>
<td>Error</td>
<td>725</td>
<td>68995.82</td>
<td>95.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>727</td>
<td>69593.21</td>
<td>95.73</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 15

**Correlations between Biology Exam Score and Spatial Factor Scores**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Items</th>
<th>r</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MRT 1-3</td>
<td>.12</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>PFT 3, 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>CRT 6, 16, 29</td>
<td>.02</td>
<td>.316</td>
</tr>
<tr>
<td>3</td>
<td>ROT 1, 3</td>
<td>.09</td>
<td>.006</td>
</tr>
<tr>
<td>4</td>
<td>HFT 1, 3</td>
<td>.08</td>
<td>.016</td>
</tr>
</tbody>
</table>

n=728

### Table 16

**Regression of Biology Achievement by Spatial Factor Scores**

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>Mult R</th>
<th>RSQ</th>
<th>F</th>
<th>Sig F</th>
<th>Beta</th>
<th>In</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fact 1</td>
<td>.12</td>
<td>.01</td>
<td>10.1</td>
<td>.002</td>
<td>.12</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Fact 3</td>
<td>.14</td>
<td>.02</td>
<td>7.1</td>
<td>.001</td>
<td>.07</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Fact 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.06</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Fact 2</td>
<td>.15</td>
<td>.02</td>
<td>4.3</td>
<td>.002</td>
<td>-.01</td>
<td></td>
</tr>
</tbody>
</table>

n=728
Relationship between Spatial and/or Analytic Ability and Biology Topic and Item Type Subscores

Pearson product-moment correlations indicate small, but highly significant, correlations between a number of the biology topic subscores and the spatial test totals. Correlation coefficients and probability values for the topic subscores are reported in Table 17. Scores on the ROT and the PFT, tests of spatial visualization, are significantly correlated with 12 out of 23 and 10 out of 23 biology topics, respectively. The analytic ability measure, the HFT, and the orientation measure, the CRT, are each significantly correlated with five of the biology topic subscores. The MRT, a spatial visualization instrument, shows significant correlations with only three biology topic subscores. The only topic subscore that is significantly correlated with all five spatial and/or analytic instruments is a subscore which includes four items dealing with environmental concerns. Four topic subscores, including food chains, protein synthesis, population dynamics, and animal phyla and their characteristics, show significant correlations with three of the spatial and/or analytic test totals. Though none of the actual test items within these subscores contain graphics, the corresponding sections in the text and the laboratory manual contain extensive figures, graphs, and diagrams to depict or explain the material. Graphics were also provided, however, for topics which do not demonstrate significant correlations with the spatial and/or analytic scores.
In the factor analysis of mixed items from the spatial and/or analytic instruments, Factor 1 includes items from the MRT and the PFT indicating that the two instruments measure a common factor. ROT items, though also designed to measure spatial visualization, load separately on Factor 3. In the analysis of topic subscores, however, only two topic subscores exhibit significant correlations with both MRT and PFT score while ROT and PFT score show overlapping significant correlations on six topic subscores suggesting that the ROT and PFT actually measure a common or similar factor.

Pearson product-moment correlations between laboratory subscores and the spatial and/or analytic test totals are reported in Tables 18 and 19. Items corresponding to the lab on organismic diversity are significantly correlated with both the ROT and the PFT. When the subscore is limited to items that refer to an actual activity performed during the lab, as indicated in Table 19, correlations with the ROT and PFT are even greater, suggesting that spatial skill is particularly important for success in the practical aspects of biology and in the application of biological concepts to concrete situations. A higher correlation with the ROT and PFT for hands-on activity items is also seen for the laboratory eight subscore which deals with plant form, function, and reproduction. Additionally, the greatest correlation (p<.000, r=.24) the PFT exhibits with any of the biology subscores is with the subscore that includes the 28 items referring to concrete activities the subjects completed during the course of the quarter. The ROT also exhibits a highly significant (p<.000, r=.21)
correlation with this subscore, again suggesting an important role for spatial visualization abilities in laboratory situations. The only laboratory subscore that is not significantly correlated with at least one of the spatial and/or analytic subscores is the Mendelian inheritance subscore. This subscore, however, consists of only one item and is not a reliable indicator of a subject's understanding of the concepts involved. Of the remaining five laboratory subscores, the ROT and the PFT are each significantly correlated with four subscores, including the dissection of invertebrates, fundamental molecular processes, cell reproduction, population genetics and evolution, and ecology. Both spatial test totals are significantly correlated with the subscores involving the dissection of invertebrates, fundamental molecular processes, and population genetics and evolution.

With respect to the other three spatial and/or analytic instruments, the MRT does not demonstrate any significant correlations with the laboratory subscores. Both the HFT and the CRT are significantly correlated with two of the laboratory subscores. However, when hands-on activity items only are considered, the HFT does not exhibit a significant correlation with any of the eight laboratory subscores.

Table 20 includes Pearson product-moment correlations between item type subscores and the spatial test totals. When items are sorted based on whether they involve a quantitative or a qualitative understanding, the quantitative subscore is significantly
correlated with both the ROT and the PFT. The qualitative subscore
is significantly correlated with ROT, PFT, and HFT scores. However,
since the qualitative subscore contains 94 of the 100 biology items,
correlations with this subscore provide information similar to the
information gained from correlations with the entire final exam. The
significant correlations found between the six-item quantitative
subscore and the spatial visualization measures, however, suggest
that spatial skill may be of particular importance in understanding
quantitative concepts in biology.

Table 20 also includes correlation coefficients obtained when
items were sorted according to the level of Bloom's (1956) taxonomy
of educational objectives represented. Only three levels of the
taxonomy (knowledge, comprehension, and application) are
represented in the final exam. The knowledge or rote memory
subscore is significantly correlated with ROT, PFT, and HFT scores.
This subscore includes 75% of the exam questions. The
comprehension subscore, a 20-item subscore, exhibits significant
correlations with the ROT, PFT, HFT, and CRT. In previous studies
(Bodner and McMillen, 1986; Carter, LaRussa, and Bodner, 1987;
and Pribyl and Bodner, 1987), correlations with spatial skill were
highest for items requiring problem solving capabilities. These items
would be included in the application level of Bloom's taxonomy. In
the present study, however, the five-item application subscore is
significantly correlated with PFT score only, with the degree of
correlation being much lower than that observed with the knowledge
and comprehension subscores. This finding suggests that spatial skill does not play an important role in problem solving ability. However, the application level subscore may not be a valid measure of problem solving ability since only a small subset of the types of items that require problem solving ability is included in the subscore. Additionally, the reliability (\( \alpha = .33 \)) of the five-item subscore is quite low. In order to clarify the nature of the relationship between spatial skill and problem solving ability, additional research is needed using more reliable measures of problem solving ability which include a broader variety of problem solving items.
Table 17.
Correlations between Biology Topic Subscores and Spatial Test Totals

<table>
<thead>
<tr>
<th>Topic</th>
<th>ROT</th>
<th>MRT</th>
<th>PFT</th>
<th>HFT</th>
<th>CRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genetic Engineering</td>
<td>.10</td>
<td>-.02</td>
<td>.13*</td>
<td>.10</td>
<td>.00</td>
</tr>
<tr>
<td></td>
<td>(p=.054)</td>
<td>(p=.366)</td>
<td>(p=.015)</td>
<td>(p=.073)</td>
<td>(p=.474)</td>
</tr>
<tr>
<td>Cell Structure</td>
<td>.10*</td>
<td>-.01</td>
<td>.12*</td>
<td>.03</td>
<td>.04</td>
</tr>
<tr>
<td></td>
<td>(p=.041)</td>
<td>(p=.451)</td>
<td>(p=.025)</td>
<td>(p=.327)</td>
<td>(p=.253)</td>
</tr>
<tr>
<td>Photosynthesis</td>
<td>.10</td>
<td>.06</td>
<td>.16*</td>
<td>.08</td>
<td>.07</td>
</tr>
<tr>
<td></td>
<td>(p=.052)</td>
<td>(p=.155)</td>
<td>(p=.005)</td>
<td>(p=.096)</td>
<td>(p=.113)</td>
</tr>
<tr>
<td>Plants</td>
<td>.07</td>
<td>-.05</td>
<td>.14*</td>
<td>.04</td>
<td>-.05</td>
</tr>
<tr>
<td></td>
<td>(p=.129)</td>
<td>(p=.205)</td>
<td>(p=.012)</td>
<td>(p=.230)</td>
<td>(p=.220)</td>
</tr>
<tr>
<td>Food Chains</td>
<td>.11*</td>
<td>.02</td>
<td>.12*</td>
<td>.09</td>
<td>.13*</td>
</tr>
<tr>
<td></td>
<td>(p=.038)</td>
<td>(p=.370)</td>
<td>(p=.002)</td>
<td>(p=.074)</td>
<td>(p=.015)</td>
</tr>
<tr>
<td>Protein Synthesis</td>
<td>.16*</td>
<td>.11*</td>
<td>.14*</td>
<td>.07</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>(p=.004)</td>
<td>(p=.032)</td>
<td>(p=.008)</td>
<td>(p=.112)</td>
<td>(p=.326)</td>
</tr>
<tr>
<td>Population Dynamics</td>
<td>.17*</td>
<td>.00</td>
<td>.14*</td>
<td>.18*</td>
<td>.05</td>
</tr>
<tr>
<td></td>
<td>(p=.002)</td>
<td>(p=.490)</td>
<td>(p=.012)</td>
<td>(p=.001)</td>
<td>(p=.187)</td>
</tr>
<tr>
<td>History of Life</td>
<td>.14*</td>
<td>.05</td>
<td>.07</td>
<td>.07</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>(p=.010)</td>
<td>(p=.186)</td>
<td>(p=.112)</td>
<td>(p=.135)</td>
<td>(p=.323)</td>
</tr>
<tr>
<td>Selection</td>
<td>.01</td>
<td>-.01</td>
<td>-.02</td>
<td>-.02</td>
<td>.05</td>
</tr>
<tr>
<td></td>
<td>(p=.422)</td>
<td>(p=.457)</td>
<td>(p=.356)</td>
<td>(p=.358)</td>
<td>(p=.192)</td>
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<td>Topic</td>
<td>ROT</td>
<td>MRT</td>
<td>PFT</td>
<td>HPT</td>
<td>CRT</td>
</tr>
<tr>
<td>-----------------------</td>
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<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
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<td>Evolution</td>
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<td>.09</td>
<td>.03</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>(p=.006)</td>
<td>(p=.362)</td>
<td>(p=.057)</td>
<td>(p=.290)</td>
<td>(p=.289)</td>
</tr>
<tr>
<td>Scientists</td>
<td>.06</td>
<td>-.01</td>
<td>.05</td>
<td>.08</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>(p=.173)</td>
<td>(p=.426)</td>
<td>(p=.223)</td>
<td>(p=.082)</td>
<td>(p=.296)</td>
</tr>
<tr>
<td>Environment</td>
<td>.23*</td>
<td>.14*</td>
<td>.16*</td>
<td>.12*</td>
<td>.15*</td>
</tr>
<tr>
<td></td>
<td>(p=.000)</td>
<td>(p=.010)</td>
<td>(p=.003)</td>
<td>(p=.024)</td>
<td>(p=.005)</td>
</tr>
<tr>
<td>Toxins/Carcinogens</td>
<td>.05</td>
<td>-.04</td>
<td>.14*</td>
<td>-.02</td>
<td>.05</td>
</tr>
<tr>
<td></td>
<td>(p=.197)</td>
<td>(p=.263)</td>
<td>(p=.011)</td>
<td>(p=.361)</td>
<td>(p=.197)</td>
</tr>
<tr>
<td>Cell Reproduction</td>
<td>.05</td>
<td>-.01</td>
<td>.12*</td>
<td>.03</td>
<td>-.01</td>
</tr>
<tr>
<td></td>
<td>(p=.181)</td>
<td>(p=.443)</td>
<td>(p=.023)</td>
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<td>(p=.409)</td>
</tr>
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<td>DNA Replication</td>
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<td>-.06</td>
<td>-.02</td>
<td>.02</td>
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<td>(p=.358)</td>
<td>(p=.044)</td>
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<tr>
<td>Nature of Science</td>
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<td>-.08</td>
<td>.03</td>
<td>.10*</td>
<td>-.03</td>
</tr>
<tr>
<td></td>
<td>(p=.499)</td>
<td>(p=.106)</td>
<td>(p=.295)</td>
<td>(p=.043)</td>
<td>(p=.290)</td>
</tr>
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<td>.02</td>
<td>.12*</td>
<td>.05</td>
<td>.01</td>
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<tr>
<td></td>
<td>(p=.391)</td>
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<td>(p=.028)</td>
<td>(p=.218)</td>
<td>(p=.428)</td>
</tr>
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<td>.00</td>
<td>.14*</td>
<td>.02</td>
<td>.14*</td>
</tr>
<tr>
<td></td>
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<td>(p=.485)</td>
<td>(p=.010)</td>
<td>(p=.349)</td>
<td>(p=.011)</td>
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<td>Topic</td>
<td>ROT</td>
<td>MRT</td>
<td>PFT</td>
<td>HFT</td>
<td>CRT</td>
</tr>
<tr>
<td>------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Prokaryotes</td>
<td>.06</td>
<td>.11*</td>
<td>.06</td>
<td>.10</td>
<td>-.06</td>
</tr>
<tr>
<td></td>
<td>(p=.106)</td>
<td>(p=.038)</td>
<td>(p=.158)</td>
<td>(p=.054)</td>
<td>(p=.173)</td>
</tr>
<tr>
<td>Communities</td>
<td>.12*</td>
<td>.04</td>
<td>.05</td>
<td>.10*</td>
<td>.04</td>
</tr>
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<td></td>
<td>(p=.019)</td>
<td>(p=.273)</td>
<td>(p=.218)</td>
<td>(p=.041)</td>
<td>(p=.255)</td>
</tr>
<tr>
<td>Genetics</td>
<td>.04</td>
<td>-.00</td>
<td>.05</td>
<td>.09</td>
<td>.04</td>
</tr>
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<td></td>
<td>(p=.254)</td>
<td>(p=.477)</td>
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<td>(p=.065)</td>
<td>(p=.242)</td>
</tr>
<tr>
<td>Population</td>
<td>.11*</td>
<td>.05</td>
<td>.07</td>
<td>.06</td>
<td>.11*</td>
</tr>
<tr>
<td>Genetics</td>
<td>(p=.032)</td>
<td>(p=.219)</td>
<td>(p=.110)</td>
<td>(p=.161)</td>
<td>(p=.030)</td>
</tr>
<tr>
<td>Biosphere</td>
<td>.05</td>
<td>.02</td>
<td>.06</td>
<td>.11*</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>(p=.200)</td>
<td>(p=.373)</td>
<td>(p=.157)</td>
<td>(p=.036)</td>
<td>(p=.282)</td>
</tr>
</tbody>
</table>

Note. *=significant at the .05 level.
Table 18.
Correlations between Laboratory Topic Subscores and Spatial Test Totals

<table>
<thead>
<tr>
<th>Topic</th>
<th>ROT</th>
<th>MRT</th>
<th>PFT</th>
<th>HFT</th>
<th>CRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organismic diversity</td>
<td>.12*</td>
<td>-.01</td>
<td>.13*</td>
<td>-.03</td>
<td>.06</td>
</tr>
<tr>
<td>Dissection of invertebrates</td>
<td>.15*</td>
<td>.05</td>
<td>.12*</td>
<td>.07</td>
<td>.12*</td>
</tr>
<tr>
<td>Molecular processes</td>
<td>.15*</td>
<td>.09</td>
<td>.11*</td>
<td>.06</td>
<td>.00</td>
</tr>
<tr>
<td>Cell reproduction</td>
<td>.07</td>
<td>.00</td>
<td>.15*</td>
<td>.07</td>
<td>.01</td>
</tr>
<tr>
<td>Mendelian inheritance</td>
<td>.09</td>
<td>-.02</td>
<td>.11</td>
<td>.03</td>
<td>.05</td>
</tr>
<tr>
<td>Pop. genetics &amp; evolution</td>
<td>.14*</td>
<td>.04</td>
<td>.12*</td>
<td>.12*</td>
<td>.12*</td>
</tr>
<tr>
<td>Ecology</td>
<td>.11*</td>
<td>-.02</td>
<td>.04</td>
<td>.12*</td>
<td>.04</td>
</tr>
<tr>
<td>Plant form &amp; function</td>
<td>.05</td>
<td>-.08</td>
<td>.10*</td>
<td>.05</td>
<td>-.03</td>
</tr>
<tr>
<td>Exclusively lab items (n=9)</td>
<td>.17*</td>
<td>-.02</td>
<td>.16*</td>
<td>.03</td>
<td>.07</td>
</tr>
</tbody>
</table>

Note. *=significant at the .05 level.
<table>
<thead>
<tr>
<th>Topic</th>
<th>Spatial Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ROT</td>
</tr>
<tr>
<td>Organismic diversity</td>
<td>.15*</td>
</tr>
<tr>
<td></td>
<td>(p=.005)</td>
</tr>
<tr>
<td>Dissection of invertebrates</td>
<td>.15*</td>
</tr>
<tr>
<td></td>
<td>(p=.005)</td>
</tr>
<tr>
<td>Molecular processes</td>
<td>.09</td>
</tr>
<tr>
<td></td>
<td>(p=.066)</td>
</tr>
<tr>
<td>Cell reproduction</td>
<td>.00</td>
</tr>
<tr>
<td></td>
<td>(p=.472)</td>
</tr>
<tr>
<td>Mendelian inheritance</td>
<td>.09</td>
</tr>
<tr>
<td></td>
<td>(p=.063)</td>
</tr>
<tr>
<td>Pop. genetics &amp; evolution</td>
<td>.11*</td>
</tr>
<tr>
<td></td>
<td>(p=.032)</td>
</tr>
<tr>
<td>Ecology</td>
<td>.13*</td>
</tr>
<tr>
<td></td>
<td>(p=.017)</td>
</tr>
<tr>
<td>Plant form &amp; function</td>
<td>.09</td>
</tr>
<tr>
<td></td>
<td>(p=.062)</td>
</tr>
<tr>
<td>Total (all hands-on items)</td>
<td>.21*</td>
</tr>
<tr>
<td></td>
<td>(p=.000)</td>
</tr>
</tbody>
</table>

Note. *=significant at the .05 level.
### Table 20.
Correlations between Item Type Subscores and Spatial Test Totals

<table>
<thead>
<tr>
<th>Item Type</th>
<th>Spatial Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ROT</td>
</tr>
<tr>
<td>Qualitative</td>
<td>.22* (p=.000)</td>
</tr>
<tr>
<td>Quantitative</td>
<td>.11* (p=.036)</td>
</tr>
<tr>
<td>Knowledge</td>
<td>.21* (p=.000)</td>
</tr>
<tr>
<td>(rote memory)</td>
<td></td>
</tr>
<tr>
<td>Comprehension</td>
<td>.21* (p=.000)</td>
</tr>
<tr>
<td>Application</td>
<td>.07 (p=.124)</td>
</tr>
</tbody>
</table>

Note. *=significant at the .05 level
Relationship between Gender and Spatial and/or Analytic Skill

The regression analysis of gender by spatial and/or analytic scores, shown in Table 21, indicates that ROT and MRT scores are significant predictors of gender with males outs coring females. CRT score is also a significant predictor of gender with females outs coring males. The results of a regression analysis of gender by factor score, provided in Table 22, mirror the regression results with the total spatial scores. Factors 1 and 3, spatial visualization, are significant predictors of gender with males outs coring females. Factor 2, spatial orientation, is also a significant predictor of gender with females scoring higher than males. Factor 4, analytic ability, is not a significant predictor of gender. Additionally, a regression analysis of gender by achievement does not indicate a significant difference (F=.063, p=.07) between the performance of males and females on the biology final examination.
Table 21
Regression of Gender by Spatial Test Totals

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>Mult R</th>
<th>RSQ</th>
<th>F</th>
<th>Sig F</th>
<th>Beta In</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ROT</td>
<td>.33</td>
<td>.11</td>
<td>87.4</td>
<td>&lt;.000</td>
<td>.33</td>
</tr>
<tr>
<td>2</td>
<td>MRT</td>
<td>.36</td>
<td>.13</td>
<td>53.2</td>
<td>&lt;.000</td>
<td>.16</td>
</tr>
<tr>
<td>3</td>
<td>HFT</td>
<td>.04</td>
<td></td>
<td></td>
<td></td>
<td>.04</td>
</tr>
<tr>
<td>4</td>
<td>PFT</td>
<td>.05</td>
<td></td>
<td></td>
<td></td>
<td>.05</td>
</tr>
<tr>
<td>5</td>
<td>CRT</td>
<td>.37</td>
<td>.13</td>
<td>22.3</td>
<td>&lt;.000</td>
<td>-.06</td>
</tr>
</tbody>
</table>

n=728

Table 22
Regression of Gender by Spatial Factor Scores

<table>
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<tr>
<th>Step</th>
<th>Variable</th>
<th>Mult R</th>
<th>RSQ</th>
<th>F</th>
<th>Sig F</th>
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<td>1</td>
<td>Fact 1</td>
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<td>2</td>
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<td>.09</td>
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</tr>
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<td>4</td>
<td>Fact 2</td>
<td>.30</td>
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n=728
Summary of Findings

1. Factor analysis results indicate that the five instruments used in the present study measure two distinct cognitive constructs. The ROT, MRT, and CRT are relatively pure measures of spatial ability, while the HFT is a relatively pure measure of analytic ability.

2. The Paper Folding Test appears to be an example of a spatial visualization measure which is confounded by analytic processing. The PFT demonstrates factor loadings of .63 and .34 on the spatial and analytic factors, respectively.

3. Spatial visualization ability is significantly and positively correlated with biology achievement in Biology 101, a course for nonmajors. Depending on the instrument used to assess spatial visualization ability, the correlation can account for up to 5% of the variance in achievement scores. Additionally, results of the regression analyses by spatial test totals and by factor scores indicate that spatial visualization ability is a significant predictor of biology achievement.

4. Analytic ability is significantly and positively correlated with biology achievement. However, results of the regression analyses by test totals and by factor scores indicate that analytic ability is not a significant predictor of biology achievement.

5. Spatial visualization ability is a significant predictor of gender, with males outscoring females.
Conclusions Regarding the Cognitive Constructs

One of the goals of the present study was to provide evidence as to whether analytic ability and spatial ability are two distinct cognitive constructs. Correlational studies of tests designed to measure the two constructs have frequently shown positive correlations between measures of spatial skill and measures of analytic skill (Linn & Kyllonen, 1981). Some researchers (Bodner & McMillen, 1986; Carter, LaRussa, & Bodner, 1987; and Linn & Kyllonen, 1981) have interpreted such correlations as evidence that analytic skill and spatial skill actually represent a single cognitive factor. Other researchers (Guay, McDaniel, & Angelo, 1978; Guay & McDaniel, 1978; and Kyllonen, Lohman, & Snow, 1984) suggest that the two factors are discrete and that positive correlations between spatial skill and analytic skill are a consequence of analytic confounding of spatial skill assessment measures. As in the pilot study, the findings of the present study support the hypothesis that spatial skill and analytic skill are two distinct cognitive factors. Although Pearson product-moment correlations between the four instruments designed to measure spatial skill (the ROT, MRT, CRT,
and PFT) and the one purported measure of analytic skill (the HFT) are statistically significant, for each of the spatial skill instruments the lowest degree of correlation is with the HFT. Moreover, a factor analysis of the five total scores indicates two separate factors. The HFT loads strongly on one factor while the four spatial skill assessments load strongly on the other factor. One of the spatial visualization measures, the PFT, loads moderately on the HFT factor. These findings suggest that the ROT, MRT, and CRT are all relatively pure measures of spatial ability while the PFT contains items which may be solved using analytic processing strategies.

Based on an analysis of subjects' self-reports of the type of processing techniques they employed, Guay, McDaniel, and Angelo (1978) concluded that the ROT and the MRT were the two tests of spatial skill out of nine studied that were the least confounded by analytic processing strategies. The results of the present study support the conclusions regarding both instruments. The present findings also support Guay, McDaniel, and Angelo's (1978) hypothesis that some of the items on instruments designed to measure spatial skill are actually measures of analytic skill, specifically with respect to the PFT. A number of other researchers (Linn & Kyllonen, 1981; Kyllonen, Lohman, & Snow, 1984; Zimowski & Wothke, 1988; and Melear, 1989) have also provided evidence that paper-folding tasks include a large nonspatial component corresponding to analytic ability.
The presence of analytic factor confounding in commonly used measures of spatial skill suggests that conclusions regarding the relationship between spatial ability and other variables, such as science achievement, are largely dependent on the instrument used to measure spatial skill (Zimowski & Wothke, 1988). Table 23 provides a list of studies in which the relationship between spatial skill and science achievement was examined. In addition to indicating the results of each study, the table also lists the instruments used to measure spatial skill in each study. Findings reported by Guay, McDaniel, and Angelo (1978) and the present researcher indicate that, in the present study, the most accurate information concerning the relationship between spatial skill and biology achievement is provided by correlation coefficients computed between ROT scores and biology achievement scores, since the ROT exhibits the strongest loading on the spatial factor and the weakest loading on the analytic factor.

Zimowski and Wothke (1988) have studied item features from various spatial skill instruments in order to identify the specific attributes associated with what they refer to as analog (spatial or holistic) solution strategies. Their list of criteria for true measures of spatial skill includes the following:

First, they involve judgments among rotated stimuli. Other transformation tasks are less resistant to solution by nonanalog processes. Second, the stimuli differ by orientation other than 180 degrees. Because simple verbal rules such as "the right side now becomes the left side" can be used to solve 180-degree items, these items tend to have a nonanalog component.
Third, when the items contain distractors, the distractors are mirror images of the reference stimuli or structurally equivalent forms. When mirror image distractors are not used, the problems are readily solved through "feature-extraction" strategies, e.g., identification of incongruent portions of the figures. Fourth, the items require whole-whole rather than part-whole or part-part comparisons. Subjects report using serial comparison or other nonanalog strategies on items that involve the latter two types of comparisons. Items requiring these types of comparisons also produce effects consistent with a nonanalog model of information processing. Fifth, analog items require the rotation of an entire object as a rigid whole rather than the rotation of only one or several pieces of the object relative to the whole. Finally, solution time restrictions are imposed on the items to inhibit solution through other than analog means. (p. 2-3)

Most of the items on the ROT match all of the attributes of pure measures of spatial skill identified by Zimowski and Wothke, with the only exception being a few items which include 180 degree rotations. This evidence, along with the present findings and those of Guay, McDaniel, and Angelo (1978), suggests that the ROT is a valid measure of spatial visualization. Therefore, future studies examining the relationship between biology achievement and spatial skill should employ the full length version of the ROT or another spatial skill assessment measure which matches the criteria identified by Zimowski and Wothke (1988) to improve the validity of conclusions linking spatial skill level with science achievement. Tests such as the PFT, which contain a large nonspatial component, jeopardize the validity of spatial skill assessments and should not be used to formulate conclusions regarding the relationship of the construct to other variables.
Conclusions Regarding the Relationship between Spatial Skill and Biology Achievement

The findings of the present study provide additional evidence supporting the hypothesis that spatial skill is positively correlated with achievement in biology. Specifically, scores on the three instruments designed to measure spatial visualization demonstrate significant correlations with the composite biology achievement score. However, although the correlation between the achievement score and PFT score is highly significant (p<.000, r=.16), this coefficient may not accurately represent the relationship between the two variables, since the PFT does not appear to be a valid measure of spatial visualization. The most accurate information regarding the relationship between biology achievement and spatial skill is provided by the correlation between ROT score and final exam score. This correlation coefficient is the largest and most highly significant (p<.000) among those computed. Additionally, the correlation between MRT score and biology achievement is also statistically significant. Factor analysis results from the present study and previous findings by Guay, McDaniel, and Angelo (1978) suggest that the MRT, like the ROT, demonstrates construct validity with respect to spatial visualization, further supporting the hypothesis that spatial visualization ability is related to biology achievement.

The findings of both the present study and the pilot study (Sutherland, 1990) do not suggest a significant relationship between
biology achievement and spatial orientation ability. Spatial orientation refers to the ability to remain unconfused when visual stimuli are presented in varying orientations (McGee, 1979). This component of spatial skill does not require the mental manipulation of three-dimensional objects, as does spatial visualization. Therefore, it is possible that positive correlations between science achievement and spatial skill, such as those reported in Table 23, are exclusively a function of a student's ability to visualize the three-dimensional concepts and structures included in science instruction. However, Pallrand and Seeber (1984) found that students with higher scores on the CRT, a test of spatial orientation, had significantly higher physics achievement scores than did students with lower spatial orientation scores. This finding suggests that the orientation component of spatial skill also contributes to success in science courses. Therefore, further research is needed to clarify the nature of the relationship between spatial orientation and biology achievement.

With respect to the visualization component of spatial skill, however, findings of the present study, as well as previous research (Lord, 1987b; and Costello, 1985), indicate a link between biology achievement and visualization scores. Additionally, Lord (1987a, 1985) reported that practice in visualization significantly improved both students' spatial abilities and their level of biology achievement. These findings suggest that biology teachers need to routinely include visualization experiences as a part of their lessons. Students
should be encouraged to practice mentally manipulating three-dimensional structures and imagining them from various perspectives as a way to enhance their visualization abilities (Lord, 1987a). The use of three-dimensional models should be included in biology instruction as it has also been shown to be an effective strategy for improving spatial visualization skills (Talley, 1973; and Small & Morton, 1983). Additionally, biology teachers should provide instruction in support strategies for dealing with questions involving three-dimensional structures. For example, Pribyl and Bodner (1987) found that high spatial ability students were more likely to draw preliminary figures when answering questions, and that students who drew preliminary figures for a problem were more likely to answer the problem correctly. Therefore, students should be encouraged to draw sketches of three-dimensional structures as they solve problems as a possible means of improving their performance. Another method biology instructors could use to assist students with low spatial abilities in understanding three-dimensional structures or concepts is to provide appropriate analogies as a topic is introduced. Russell-Gebbett (1985) reported that students who were successful in interpreting three-dimensional structures often compared the structures to familiar and analogous structures such as household items. It might be helpful to students with low levels of spatial ability if such comparisons were provided by the instructor.
The ability to interpret various sectional views of biological specimens is a critical component of virtually all undergraduate biology courses (Bishop, 1978). Although there were no exam questions dealing with sectional views in the present study, in the pilot study significant positive correlations with spatial visualization were found for the laboratory exam ($r=.40$, $p=.003$) and the laboratory practical ($r=.28$, $p=.028$), both of which contained items requiring the recognition or interpretation of sectional views of three-dimensional specimens. Additionally, in a study of the specific spatial skills necessary for success in biology courses, Macnab and Johnstone (1990) found that students encountered more difficulty visualizing a two-dimensional section cut from a three-dimensional structure than visualizing a three-dimensional object from two-dimensional sections. These findings suggest that it is inappropriate for biology instructors to present three-dimensional structures and assume that their students will be able to visualize sectional views. Instead, teachers need to assist students in dealing with sectional views by presenting a variety of support strategies such as the use of models and analogies. Lord (1987b) suggests that three-dimensional models be presented at angles different from the two-dimensional figures included in the textbook. He also suggests that:

When we question students about their biological understanding, we should ask them how a sample or a slide fits into the organism or the larger sample. After dissections, students should try returning the organs to their original positions. And they should discuss the dissection procedure by describing the relative location of the organs. (p. 34)
Biology instruction focusing on the development of spatial skills should not be limited to topics involving three-dimensional structures. Lord (1987b) found that students with low levels of spatial skill had difficulty interpreting diagrams, graphs, charts, and tables. He recommends that:

Students must continually be urged to use their imagination, to visualize situations and predict outcomes. We should devote more time to charts, graphs, and diagrams so students can more easily develop mental images of the events depicted by the data. (p. 34)

Developing the ability to comprehend charts and graphs is particularly important since students will continue to encounter them in other academic disciplines and in their daily lives as citizens and consumers.

One of the goals of the present study was to identify specific concepts and/or item types which require spatial visualization abilities, with the ultimate goal of developing instructional materials and methods which would enable students with low levels of spatial skill to be successful in these areas. Though significant positive correlations with spatial visualization are evident for a number of the topic subscores, the amount of variance explained in each case is less than five percent. Additionally, in many cases, correlations with visualization are higher for topics involving nonspatial content (such as the history of life) than for topics including a large spatial component (such as cell reproduction and DNA replication). One possible explanation for these findings is that the reliability for the
biology topic subscores is quite low, exceeding .50 for only one of twenty-three subscores. Another confounding factor is that the achievement items were developed by the course instructor and subsequently sorted into topic subscores by the researcher. Topic subscores, therefore, do not contain the same number of items and may include items which could also be appropriately included in other topic subscores. Additionally, the majority of the items (75 out of 100) require students to function only at the level of rote memory, and do not test for a complete understanding of spatial concepts or three-dimensional structures. Because previous research (Costello, 1985) has indicated that the spatial requirements of an item vary depending on the content involved, further research is warranted to uncover the particular biological concepts that require well-developed spatial abilities. However, in order to validly represent the relationship between visualization skill and ability to learn particular biological concepts, future studies need to include reliable achievement measures containing items designed to test for a complete understanding of the concepts involved.

With respect to the relationship between particular items types and spatial skill, previous studies (Bodner & McMillen, 1986; Carter, LaRussa, & Bodner, 1987; and Pribyl & Bodner, 1987) have indicated that spatial skill plays a more important role in the successful completion of problem solving items than in the completion of items at the knowledge or rote level of cognitive functioning. It has been suggested (Bodner & McMillen, 1986) that spatial abilities are
required to complete the initial stages of problem solving which involve disembedding relevant information from the problem and restructuring it into an easier task. Talley (1973) reported that students who participated in a spatial intervention program were more successful at completing items from the application, analysis, and evaluation levels of Bloom's (1957) taxonomy than were students in a control group, supporting the hypothesis that spatial skill is involved in higher order cognitive tasks such as problem solving. In the present study, however, the knowledge and comprehension level subscores demonstrate correlations with ROT score of an equivalent level of significance, while the application level subscore is not significantly correlated with spatial visualization, as measured by either the ROT or the MRT.

One possible explanation for conflicting results is that the number of items per item type subscore in the present study is extremely unbalanced (n=75 for the knowledge level, n=20 for the comprehension level, and n=5 for the application level). Additionally, the application subscore provides an extremely minimal measure of a subject's ability to complete higher order cognitive tasks such as problem solving. However, conflicting research results may also be a function of the various instruments used to measure spatial skill in each study. For example, one of the instruments used in Talley's (1973) study to assess spatial skill level was the Paper Folding Test, an instrument which is not a factor-pure measure of the construct. Additionally, in the Bodner and McMillen
(1986) and Pribyl and Bodner (1987) studies, spatial skill level was determined by combining scores on the ROT and the Find-a-Shape Puzzle, a test of analytic ability, into a single score. Findings of the present study suggest that spatial ability and analytic ability are two distinct cognitive constructs, indicating that the conclusions of previous studies regarding the relationship of spatial skill to problem solving may not be valid. Additional research is needed, therefore, to determine the relationship between spatial ability and ability to function at higher cognitive levels. In order to accurately describe this relationship, future studies need to employ measures of spatial skill which demonstrate construct validity and measures of achievement which assess higher order cognitive functioning using a wide variety of problem solving items.

Conclusions Regarding the Relationship between Analytic Ability and Biology Achievement

As in the pilot study (Sutherland, 1990), the hypothesis that analytic ability is related to success in a non-majors biology course is not supported by the present findings. In the regression analysis of biology achievement by spatial and/or analytic test totals, HFT score is not a significant predictor of achievement. Additionally, although HFT score is significantly and positively correlated with final exam score, the correlation coefficient is only .09, indicating that analytic ability explains less than one percent of the variance among achievement scores. When achievement results are examined by
topic, HFT score demonstrates significant correlations with only five of twenty-three subscores.

Although the present findings do not suggest a link between analytic ability and science achievement, previous research has indicated a significant relationship between the two variables. For example, Costello (1985) reported that scores on a test of disembedding (analytic) ability loaded on the same factor as genetics test items involving the calculation of map units. In the area of chemistry, Pribyl and Bodner (1987) found that scores on the Find-A-Shape-Puzzle, a test of disembedding ability, were positively and significantly correlated with scores on fifteen out of twenty organic chemistry exams from four different classes of undergraduates. Similarly, Carter, LaRussa, and Bodner (1987) reported positive and significant correlations between Find-A-Shape-Puzzle scores and chemistry exam scores for ten out of eleven exams given to three groups of undergraduates. A similar relationship between disembedding or analytic ability and biology achievement is not supported by the present findings. The situation is further complicated by studies (Bodner & McMillen, 1986; and Lord, 1987a) in which scores on tests of disembedding ability were combined with scores on tests of spatial visualization to yield a total "spatial" score which was found to be significantly related to science achievement. Since the findings of the present study indicate that disembedding ability represents a construct separate from spatial ability, it is unclear whether these studies indicate a significant relationship
between analytic ability and science achievement or spatial ability and science achievement.

Due to conflicting research results and past confusion over the construct represented by tests of disembedding ability, such as the HFT and the Find-A-Shape-Puzzle, additional research is needed to clarify the nature of the relationship between analytic ability and biology achievement. Establishing whether the two variables are positively related is especially important in light of past findings (Bodner & McMillen, 1986; Carter, LaRussa, & Bodner; and Pribyl & Bodner, 1987) linking disembedding ability with problem solving ability.

Pallrand and Seeber (1984) found that physics students' scores on the HFT improved significantly following a specific intervention program. Additionally, HFT scores of a control group also improved following a semester of physics instruction. These findings indicate that analytic ability, like spatial ability, is actually a skill that can be enhanced through training and, perhaps, as a consequence of science instruction. If analytic ability is, in fact, an essential component of problem solving ability, then science courses at all levels should include instruction directed specifically at improving students' analytic abilities, with the ultimate goal of improving students' abilities to solve problems. This is especially important since the ability to complete problem-solving tasks is a critical component of success in many academic disciplines and careers, in addition to contributing to success in the sciences.
Conclusions Regarding the Relationship between Gender and Spatial Skill

Consistent with pilot results (Sutherland, 1990) and reports from other studies of spatial skill (McGee, 1979) the average performance on the spatial visualization measures is higher for males than for females. The finding of a higher mean for females on the CRT, a test of spatial orientation, is unexpected based on reports in the spatial skill literature. However, since the data indicate that it is spatial visualization which is significantly correlated with biology achievement rather than spatial orientation, the underlying reasons behind the observed gender difference in spatial visualization should be a priority in future research.

From the time the existence of the spatial visualization factor was first established in the mid-1920s, male superiority on spatial visualization tasks has been widely documented in the cognitive psychology literature (McGee, 1979). Explanations for the reasons underlying the observed gender differences in this skill have included hormonal, genetic, neurological, and environmental factors. More recently, however, the existence of sex differences in spatial performance has been questioned due to inconsistent findings across studies (Caplan, MacPherson, & Tobin, 1985). Instead, it has been hypothesized that gender differences in spatial skill are dependent upon the nature of the task used to assess spatial skill (Sharps & Gollin, 1987; and Goldbeck, 1986), and that sociocultural influences
may determine whether such differences develop (Guay & McDaniel, 1982). For example, Goldbeck (1986) found that when spatial tasks were modified to exclude physical content, gender differences in spatial ability were substantially reduced. The researcher suggested that male superiority on spatial visualization measures which include a physical component is a consequence of males having more experience in manipulative, hands-on activities.

The hypothesis that gender differences in spatial skill are task-dependent is also supported by studies employing gender-neutral spatial assessments in which no gender differences were observed. For example, Sharps and Gollin (1987) administered several spatial skill tests, including the MRT, and found that males and females performed equally as well on all measures, with the exception of an overhand throwing task which is more likely to have been practiced by males. However, other researchers (Guay & McDaniel, 1982; Carter, LaRussa, & Bodner, 1987; Pribyl & Bodner, 1987; Lord, 1987a; and Sutherland, 1990) have reported significant gender differences in favor of males on tasks devoid of physical content, such as the ROT and MRT, suggesting that gender differences in spatial skill exist regardless of the nature of the task.

Findings indicating male superiority on gender-neutral spatial tasks suggest a need for further research examining the causes for the gender differences, especially when viewed in concert with findings linking science achievement with spatial ability. Such research may suggest methods of improving the academic
performance of women in science courses. This is particularly important at the college level in light of Miller's (1989) finding that males are significantly more likely than females to be scientifically literate, even when both complete an equivalent number of college level science courses.

In addition to improving the academic performance of women enrolled in undergraduate science courses, future research may suggest ways to increase the number of women who select careers in scientific and technological fields. Although it is obviously too simplistic to attribute the relative dearth of women in science entirely to deficiencies in spatial abilities, research indicates that it is a contributing factor and, therefore, worthy of further study (Baker & Belland, 1988).

Finally, although the most beneficial time to encourage the development of spatial skill in females is earlier in life, further research exploring potential means of spatial skill remediation is especially warranted at the college level because that is where elementary education majors, who are mostly female (Baker & Belland, 1988), will receive their last formal science instruction. Surveys (Weiss, 1987) of elementary teachers indicate that many of them feel uncomfortable and inadequate in the area of science, leading them to devote less time to science instruction. It is possible that a portion of their discomfort stems from difficulties in performing visualization tasks. It is especially important to uncover methods of helping these women develop successful ways of dealing
with spatial tasks, particularly in the area of science, since they will ultimately be responsible for both guiding the spatial development and providing the first exposure to science for hundreds of individuals (Goldbeck, 1986).

Summary

The findings of the present study provide further support for the hypothesis that spatial skill is significantly correlated with biology achievement in a nonmajors biology course. In addition to the findings of the present study, significant positive correlations between spatial visualization and biology achievement have been reported by Lord (1987b) and Costello (1985). Future research is needed, however, to identify the specific concepts within the field of biology that require spatial visualization skills. In a study of the relationship between spatial skills and genetics items, Costello (1985) found that scores on the Paper Folding Test, a spatial visualization measure, loaded on the same factor as five genetics items. Other items did not load with the spatial visualization measure suggesting that spatial visualization skills are important in learning some, but not all, biological concepts. Further studies examining individual biology items are needed to clarify which concepts require spatial visualization strategies.

Further research is also needed to identify the types of items on biology assessment measures that require well developed visualization abilities. Lord's (1987b) findings suggest that items
which refer to graphics are difficult for students with low levels of spatial skill. Findings from studies of chemistry achievement (Talley, 1973; Bodner & McMillen, 1986; Carter, LaRussa, & Bodner; and Pribyl; & Bodner, 1987) suggest that students who have lesser developed spatial skills have difficulty completing items involving higher order cognitive processes. Additional research is needed to clarify the relationship between item type and spatial skill level in the area of biology.

In addition to identifying the particular concepts and/or types of items which require spatial visualization skills, another goal of future research should be the identification of activities and the development of teaching materials and methods which are effective in improving students' spatial skills and their understanding of spatially oriented biology concepts. Lord (1985, 1987b) found an intervention which required individuals to visualize the two-dimensional section resulting from the intersection of a plane and a three-dimensional solid to be effective in improving students' spatial visualization scores. This type of intervention is directed entirely at the development of spatial skill and does not address the relationship between visualization and concepts in biology. Further research is warranted to uncover methods of teaching biology which effectively assist students with low levels of spatial skill both in learning spatially oriented biology concepts and in developing their spatial visualization skills.
Overall, the findings of the present study indicate that knowledge of a student's spatial skill level can be used to identify students who are "at risk" of low achievement in biology. Once such students have been identified, teaching materials and methods which effectively assist these students in understanding biology topics and achievement items which require spatial visualization abilities need to be provided. This type of intervention program is likely to increase the achievement levels of undergraduates enrolled in nonmajors biology courses. Improving the achievement levels of undergraduates could contribute directly to increasing the level of scientific literacy in the general population. It could also indirectly impact scientific literacy rates by encouraging undergraduates to take additional science courses. Because the percentage of undergraduates who are nonscience majors has been on the rise since 1986 (Massey, 1989), it is particularly important to uncover ways to help nonmajors achieve success in introductory science courses. The findings of the present study suggest that the development of spatial visualization skills may provide one way to significantly improve the performance of students enrolled in a nonmajors biology course. Continued research is necessary for the development of a more complete understanding of the relationship between spatial visualization and biology achievement, as well as the teaching strategies and materials which are most effective in expressing this relationship.
APPENDIX A

Lecture Section A Final Exam

1. According to Roger Beachy, traditional breeding for viral resistance in plants is 5-7 years. Using genetic engineering, the time period shrinks to:

   a. 1 month  
   b. 6 months  
   c. 9-12 months  
   d. 3-4 years

2. The insertion of one or more genes into an organism to correct a genetic defect is called:

   a. tissue culture  
   b. restriction length polymorphism  
   c. gene therapy  
   d. all of the above

3. In class, we discussed that most detrimental traits are selected out, yet selection and balanced polymorphism can occur. An example of this is:

   a. sickle cell anemia  
   b. AIDS  
   c. black plague  
   d. surviving lectures and labs in Bio. 101
4. Currently, for broadleaf plants, the vector used for transporting a gene into a plant is:
   a. retrovirus
   b. Agrobacterium tumefaciens
   c. shotgun
   d. a cell from a grass plant

5. There are 3 major modes of speciation. Which of the following terms is applied to speciation which occurs as a result of geographic separation, and is a major reason for biological diversity?
   a. allopatric
   b. parapatric
   c. sympatric
   d. speciation

6. As population density increases, the chance of _______ also increases.
   a. parasitism
   b. pathogens
   c. predation
   d. competition
   e. all of the above

7. If a parent cell has 16 chromosomes and undergoes meiosis, the resulting cells will have how many chromosomes?
   a. 64
   b. 32
   c. 16
   d. 8

8. Blase is doing an experiment on children suffering from combined immuno-deficiency (SCID). He is taking cells from the patient and inserting a new gene to correct the problem. What is the gene?
a. Beta-lacomase (BLA)
b. botulism gene (BGE)
c. adenosine deaminase (ADA)
d. beta globulin (BAG)

9. In genetic engineering, with its vast potential for alleviating human misery, the question of "influencing human evolution" is most appropriately applied to engineering of:

a. somatic cells
b. germ cells
c. neurons
d. white blood cells

10. If divergence occurs in a species where interbreeding does not occur, we have:

a. a new species
b. an interesting situation
c. the same species
d. hybrids of the same species

11. A population that is growing exponentially in the absence of limiting factors can be illustrated by which type of curve:

a. S-shaped
b. J-shaped
c. one that terminates in a plateau
d. bimodal
e. binomial

12. Which of these is a habitat?

a. scavenger
b. saprophyte
c. forest
d. producer
e. decomposer
13. Mitochondria are important organelles because they:
   a. capture photons from light sources
   b. assemble proteins
   c. transport lipids
   d. breakdown carbohydrates for energy
   e. none of the above

14. A population that exceeds the carrying capacity (K) significantly will most likely:
   a. stabilize
   b. decrease drastically (crash)
   c. keep increasing
   d. will drop slightly below the carrying capacity

15. Frost damage can be caused by bacteria (ice-nucleation). Genetically engineered bacteria that protect plants have the ice nucleating gene:
   a. deleted
   b. added
   c. moved to another chromosome
   d. all of the above

16. The genetic disorder in which deformed red blood cells clot capillaries and inhibit the flow of oxygen and carbon dioxide is called:
   a. malaria
   b. hemotoxin syndrome
   c. bubonic plague
   d. sickle cell anemia
   e. toxic shock syndrome

17. In mitosis, if a parent has 16 chromosomes, each new daughter cell will have how many chromosomes?
   a. 64
   b. 32
18. Do corporations or private businesses have the right to patent new life forms?
   a. yes
   b. no
   c. has not been defined yet

19. New combinations of genes may be produced by:
   a. Chromosomal aberrations
   b. mutation
   c. crossing over
   d. sexual reproduction
   e. all of the above

20. Which statement best describes what occurs to female egg cells during meiosis?
   a. all eggs produced are viable and described as polar bodies
   b. one mature egg is produced with 3 nonviable eggs
   c. sperm is formed
   d. zygote

21. The scientist(s) who proposed the concept of the double helix was (were):
   a. Avery and Smith
   b. Watson and Crick
   c. Rosalind Franklin
   d. Johann Miescher
   e. Lennon and McCartney
22. A group of individuals of the same species occupying a given area is termed:
   a. population
   b. community
   c. ecosystem
   d. biosphere

23. The distribution of the human population in the United States is:
   a. clumped
   b. random
   c. uniform
   d. constant

24. The biosphere is characterized by:
   a. interdependency
   b. energy flow
   c. mineral cycles
   d. diversity
   e. all of the above

25. If R is dominant to r, the offspring of the cross of RR x rr will:
   a. be homozygous
   b. exhibit the same phenotype as the RR parent
   c. exhibit the same phenotype as the rr parent
   d. have the same genotype as the RR parent
   e. have the same genotype as the rr parent

26. The light-independent reactions of photosynthesis require all of the following except:
   a. ATP and NADPH
   b. carbon dioxide
   c. ribulose biphosphate (RuBP)
   d. oxygen
27. A pollen grain has:
   a. antipodal cells
   b. an egg cell inside
   c. synergids
   d. a tube nucleus

28. The location of a gene on a chromosome is its:
   a. centromere
   b. locus
   c. autosome
   d. allele

29. Starfish exhibit what kind of body symmetry?
   a. asymmetry
   b. radial symmetry
   c. bilateral symmetry
   d. none of the above

30. Mycorrhizae and plants exhibit:
   a. mutualism
   b. parasitism
   c. commensalism
   d. competition

31. DNA is best described as being composed of:
   a. 5-carbon sugar, phosphate group, protein
   b. 5-carbon sugar, carbon group, base
   c. 5-carbon sugar, phosphate group, base
   d. 3-carbon sugar, phosphate group, base
32. The process of meiosis:
   a. occurs in somatic cells only
   b. occurs in germ cells only
   c. results in two diploid daughter cells
   d. results in four diploid daughter cells

33. In prokaryotic cell reproduction (fission) the DNA molecules are attracted to:
   a. plasma membrane
   b. spindle fibers
   c. nucleus
   d. centriole

34. DNA replication occurs:
   a. in late interphase
   b. in early prophase
   c. in metaphase
   d. in anaphase
   e. in telophase

35. Crossing-over is one of the most important events in meiosis because:
   a. it produces new arrays of alleles on chromosomes
   b. homologous chromosomes must be separated into different daughter cells
   c. the number of chromosomes is halved
   d. chromatids must be separated
   e. a train might be coming

36. Snails, clams and squids belong to:
   a. Phylum Arthropoda
   b. Kingdom Monera
   c. Phylum Mollusca
   d. Class Mammalia
37. The Hardy-Weinberg equilibrium is used as a baseline for:
   a. estimating heights
   b. estimating energy expenditure
   c. measuring evolutionary change
   d. none of the above

38. Which of these factors leads to a change in gene frequency and, therefore, violates the assumptions of the Hardy-Weinberg principle?
   a. natural selection
   b. migration
   c. genetic drift
   d. all of these

39. The RNA molecule has how many strands?
   a. 1
   b. 2
   c. 3
   d. 6
   e. 141

40. The form of RNA that carries the code from the DNA to the site where the protein is assembled is called:
   a. messenger RNA (mRNA)
   b. nuclear RNA (nRNA)
   c. ribosomal RNA (rRNA)
   d. transfer RNA (tRNA)

41. The portion of the DNA molecule that is not translated and is a noncoding portion of DNA is known as a(n):
   a. intron
   b. exon
   c. deadon
   d. anticodon
42. Which of the following is not a description of a dose curve?

a. no effect
b. initially no effect, but with increasing doses a detrimental effect occurs
c. no threshold value (carcinogenic)
d. initially a positive effect, but with increasing dose a detrimental effect occurs
e. none, all of the statements are true

43. Which of these is not a function of roots?

a. absorption of water, minerals and oxygen
b. transpiration
c. storage of carbohydrates
d. physical support of the plant

44. If two genes are on the same chromosome:

a. they are in the same linkage group
b. they assort independently
c. they split in half during meiosis, going to separate chromosomes
d. none of the above

45. Which of the following is a dicot characteristic?

a. parallel leaf veins
b. one cotyledon
c. petals in multiples of four or five
d. petals in multiples of three

46. Among the concerns over animal testing are which of the following:

a. it may not reflect human response
b. total maximum dose may result in overload of animal defense systems, resulting in death
c. the source of animals, and therefore their pedigrees, is not known
47. A bluebird building a nest in a maple tree would be what type of interaction?

a. mutualism  
b. commensalism  
c. predation  
d. parasitism  
e. reductionism

48. Malaria is caused by:

a. a bacterium  
b. a protozoan  
c. algae  
d. mold  
e. a virus

49. If the rate of transpiration of a plant were increased, we would expect that:

a. the movement of gases in the phloem would increase  
b. the movement of gases in the xylem would decrease  
c. the rate of water movement in the xylem would increase  
d. no change would occur

50. GAIA is a term used to describe:

a. an old type of Volkswagen  
b. an acronym for Gals Against Intelligent Animals  
c. the ozone and greenhouse effect  
d. Mother Earth, a single, living entity

51. DDT was found to have detrimental effects on the environment. Some of these included:

a. the death of non-target organisms  
b. a reduction in some bird populations due to thin eggshells
c. the development of resistant mosquito strains
d. the death of fish at high concentrations
e. all of these

52. A plant that grows non-parasitically on another plant is called a(n):

a. epiphyte
b. saprophyte
c. bryophyte
d. bryozoan

53. In a monocot stem, the vascular tissue is:

a. scattered
b. arranged in a circle
c. x-shaped
d. none of the above

54. Which of these is an organ unique to the squid?

a. crop
b. ink sac
c. brain
d. mouth

55. Which of these individuals is recognized as the originator of the theory of evolution by natural selection?

a. Jean-Baptiste Lamarck
b. Marie Curie
c. Charles Darwin
d. Carolus Linnaeus

56. After copulation, an earthworm stores sperm in the:

a. seminal vesicle
b. seminal receptacle
c. vas deferens
d. gizzard
57. Spherical bacteria are called:
   a. bacilli
   b. spirilli
   c. cocci
   d. bacteriophages
   e. viruses

58. Materials such as RNA leave the nucleus through:
   a. nuclear exits
   b. nuclear carousels
   c. nuclear proteins
   d. nuclear pores
   e. nuclear stomata

59. All of the following organelles are involved in the cytomembrane system except:
   a. lysosomes
   b. Golgi bodies
   c. mitochondria
   d. endoplasmic reticulum
   e. microbodies

60. Photorespiration will occur:
   a. when oxygen level is high compared to carbon dioxide level
   b. when carbon dioxide level is high compared to oxygen level
   c. when oxygen level equals carbon dioxide level

61. $C_3$ and $C_4$ plants are similar in that:
   a. both have a Calvin cycle
   b. they fix carbon dioxide at the same site in the plant
   c. they use the same amount of ATP
   d. they use the same amount of water
62. During the light-dependent reactions of photosynthesis:
   a. carbon dioxide is fixed
   b. light energy is released
   c. electron and hydrogen transfers lead to ATP and NADPH formation
   d. birth is given

63. The two types of angiosperms are:
   a. monocots and dicots
   b. tricots and dicots
   c. adventitious and primary
   d. meristematic and peristaltic

64. The ability to acquire, store, transfer, or utilize energy is called:
   a. biochemistry
   b. photosynthesis
   c. metabolism
   d. respiration
   e. phosphorylation

65. Which of the following is not a characteristic of the Phylum Arthropoda?
   a. jointed appendages
   b. radial symmetry
   c. chitinous exoskeleton
   d. tagmosis

66. A species is defined by which of the following parameters?
   a. capable of interbreeding
   b. capable of producing fertile offspring
   c. isolated from other populations
   d. a and b
   e. all of the above
67. Which of the following statements is true?
   a. acute toxicity refers to damage from repeated exposures at small doses
   b. all chemicals are harmful under some conditions, but none are harmful under all conditions
   c. table salt is safe to everyone at all dose levels
   d. humans have no biological defense against chemicals

68. In order to arrive at a solution to a problem, a scientist usually proposes and tests:
   a. laws
   b. theories
   c. hypotheses
   d. principles
   e. facts

69. The organisms responsible for breaking down organic wastes in complex food webs are known as:
   a. parasites
   b. primary producers
   c. decomposers
   d. predators

70. Your lecturer's name is spelled:
   a. Danneberger
   b. Dannenberger
   c. Danneburger
   d. Dan E. Burger

71. The term "origin," when used with regard to DNA, is a reference to:
   a. the Big Bang, 12 billion years ago
   b. the point where two bases are joined
   c. the backbone of the DNA molecule
   d. starting point of DNA replication
72. The earthworms dissected in lab were:
   a. hermaphroditic and segmented
   b. unsegmented and hermaphroditic
   c. segmented and the sexes were separate
   d. unsegmented and the sexes were separate

73. Mutation is important in evolution and adaptation because:
   a. it can lead to disease
   b. it is usually recessive
   c. it introduces new combinations of genes and genetic variation
   d. it causes all organisms carrying the mutation to die

74. Crossing-over of non-sister chromatids takes place during:
   a. anaphase I
   b. telophase I
   c. prophase I
   d. telophase II

75. The hole in the ozone layer is caused solely by man-made substances (CFCs).
   a. true
   b. false

76. Which of the following is not a fruit?
   a. cucumber
   b. pumpkin
   c. sweet potato
   d. snow pea pod

77. When evaluating a daily intake of a substance, an important factor that is included is:
   a. an age factor
   b. a sex factor
78. Neutral gene mutations:
   a. are not subject to natural selection
   b. have no effect on phenotype
   c. occur at a regular rate in proteins
   d. are used in DNA clocks
   e. all of the above

79. The greenhouse effect is:
   a. a cooling of the earth due to heat from the sun being screened out
   b. a warming of the earth due to an increase in certain gases that cause heat to be retained
   c. a warming of the earth due to a sudden increase in man-made products that cause holes in the atmosphere
   d. none of the above

80. The difference in appearance of the male and female is known as:
   a. polymorphism
   b. sexual dimorphism
   c. the dioecious condition
   d. a primary sexual characteristic

81. As discussed in lecture, the most toxic chemical is:
   a. natural
   b. synthetic
   c. diazinon
   d. none of the above

82. The edict which states that if a chemical is found to be a carcinogen at any concentration it cannot be used as a food additive, is referred to as:
a. Friends of the Earth clause
b. Baldwin clause
c. Delaney clause
d. Mutagen and carcinogen clause
e. Santa clause

83. An important measure in deciding if the greenhouse effect is occurring is:

a. screaming that it is
b. measure land temperatures
c. measure ocean temperatures over time
d. none of the above

84. Directional selection occurs when:

a. the environment controls which organisms will survive
b. humans determine which organisms will survive
c. the extremes of a population have a better chance to survive
d. the organisms on one extreme of a population have a better chance to survive than those on the other extreme

85. Evolution:

a. can lead to new species
b. does not have to lead to new species
c. has nothing to do with speciation
d. a and b
e. none of the above

86. From Berra: the age of the earth has been demonstrated to be:

a. 3000 years
b. about 10 million years
c. about 4.5 billion years
c. less than a billion years
e. 6,238 years
87. Disruptive selection:
   a. favors intermediate traits
   b. favors extreme traits
   c. results in steady, directional shift of alleles

88. The construction of a polypeptide chain is done in the:
   a. nucleus
   b. Golgi bodies
   c. cytoplasm
   d. chloroplast

89. Which of the following carries amino acids to ribosomes, where amino acids are linked to the primary structure of a polypeptide?
   a. mRNA
   b. nRNA
   c. tRNA
   d. rRNA

90. In college, Charles Darwin studied to be a:
   a. doctor
   b. lawyer
   c. botanist
   d. clergyman

91. Plants need which of the following to carry out photosynthesis?
   a. carbon dioxide and water
   b. nitrogen and hydrogen
   c. oxygen and carbon dioxide
   d. water and oxygen
   e. ribose and carbon dioxide
92. Evolution is:

a. change in gene frequency due to the absence of natural selection
b. change due to a war
c. change in gene frequency brought about by natural selection
d. change in population size due to famine

93. Experiments done by Stanley Miller and Harold Urey to simulate the conditions present in the early days of the Earth produced:

a. amino acids
b. Diet Pepsi
c. nothing
d. life itself (DNA)

94. A new species can occur due to:

a. polymorphism
b. sexual polymorphism
c. alleploidy
d. trisomy

95. The rate of increase for a population (R) refers to what kind of relationship between birth rate and death rate?

a. their sum
b. their product
c. the doubling time between them
d. the difference between them
e. reduction in each of them

96. Chromosomes:

a. are DNA with associated proteins
b. contain heritable traits
c. occur in the same number in each somatic cell
d. all of the above
97. What is the "workhorse" of plant and bacterial engineering?
   a. DNA
   b. plasmid
   c. RNA
   d. donkey with some restriction enzymes

98. In the food chain, grass->rabbit->eagle, the reaction between the grass and the eagle is:
   a. predation
   b. commensalism
   c. competition
   d. neutral

99. In recombinant DNA the enzyme used to solidify (cement the ends) of the desired gene into a plasmid:
   a. DNA polymerase
   b. ligase
   c. primer
   d. promoter

100. All animals are:
    a. multicellular, heterotrophic and diploid
    b. multicellular, heterotrophic and haploid
    c. multicellular, autotrophic and diploid
    d. multicellular, autotrophic and haploid
LIST OF REFERENCES


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